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TITLE: Evaluation of Extended-wear Hearing Aid Technology for Operational Military Use

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14. ABSTRACT The primary goal of this research effort is to determine the potential viability of the Lyric device both as a deployable hearing aid for Service Members with existing hearing loss and, in the future, as a possible form factor for a transparent hearing protection device that could protect the hearing of normal-hearing listeners without degrading auditory situational awareness. Electroacoustic magnetic interference testing demonstrated no measurable interference between the Lyric device and common military communication transmission frequencies. Preliminary testing on one subject suggests a moderate amount of attenuation when the device is worn in the "off" condition, primarily above 1000 Hz; attenuation is increased to typical "double hearing protection" values with use of traditional earmuffs or earplugs. Additionally, preliminary testing on one subject suggests preservation of sound localization cues similar to an open ear condition when tested in the active mode presumably due to maintenance of hearing thresholds through 12-14 kHz when in the active mode. While still preliminary, these results suggest the Lyric device has the potential to provide hearing protection and amplification for Service Members for mild hearing loss while maintaining a higher level of situational awareness than most, if not all, currently available hearing protection systems.					
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Introduction: The purpose of the proposed study is to assess the potential military utility of a new hearing aid technology called “extended-wear” that allows a hearing aid to be inserted deeply in the ear canal and left in place continuously for up to 120 days before requiring removal and replacement. We hypothesize that this new extended-wear hearing device can, with little or no modification, be adapted to provide a treatment option for hearing loss that will allow soldiers with mild-to-moderate hearing loss to return to full duty in military environments where standard hearing aid use is not practical. We also hypothesize that, in the longer term, the technologies associated with the extended-wear hearing aid could be adapted to provide long-term hearing protection for listeners with normal hearing with minimal impact on auditory situational awareness and minimal annoyance due to factors related to occlusion, comfort, and device maintenance. We believe that such a system, if it could be achieved, could largely eliminate noise induced hearing loss in battlefield military operations.

Keywords: Hearing aid, situational awareness, Lyric, attenuation, protection, auditory localization, communication, hearing protection, hearing loss, noise exposure, occlusion

Accomplishments:

What were the major goals of the project?

The purpose of this project is to evaluate the potential military utility of the technologies embodied in the revolutionary new “extended-wear” hearing aid. A total of six different types of evaluations will be performed as part of this effort:

- 1) Evaluate the impact of the devices on sound localization accuracy
- 2) Evaluate the effect of the devices on occlusion and speech communication in noise
- 3) Evaluate how well the devices can protect the ear from blast exposure
- 4) Evaluate how well the devices can protect the ear from noise exposure
- 5) Evaluate device compatibility with existing military communication systems
- 6) Evaluate user acceptability of the devices in the hearing-impaired military population

What was accomplished under these goals?

Human Research Protocol: An existing protocol used in the routine evaluation of hearing protection devices at the Air Force Research Laboratory (AFRL), Battlespace Acoustics Branch has been updated and approved to include the Lyric device. The AFRL protocol was sent to the Human Research Protection Office (HRPO) at the US Army Medical Research & Materiel Command (USAMRMC) in June 2015 for final approval before human testing can begin.

Electromagnetic Interference (EMI) Testing: The EMI Research Laboratory at AFRL completed studies in accordance with MIL-STD 461F, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment (2013) on the Lyric device, including testing for radiated emissions and interactions with electric fields. Completion of EMI testing was necessary prior to measurements with human subjects using military communication systems and radios to determine if Lyric users would experience significant interference (i.e., audible squelching or buzzing of device) when using wired and wireless communications devices. The Lyric device passed all required tests per the MIL-STD; minor distortion was observed during the 1 to 2 GHz scans, however, the noise was not audible to the laboratory examiners. The full report is attached as Appendix 1.

Test Plan: A comprehensive test plan is complete for the measurements at AFRL, which will incorporate goals 1-2 and 4-5 above using a normal hearing population; see Table 1 for details. All components of the test plan are ready to start human testing, with the exception of the speech intelligibility sections. The speech intelligibility sections require further modification of the current facilities and equipment before subject testing can begin, specifically for presentation of recorded noise and vocal effort measurement. Finalization of the speech intelligibility sections is expected within the next three months.

Table 1: Test Plan Overview

Session:	Study Section:	Measurements, Subject 1: 0800-1330	Estimated Time: (minutes)	Facility:	Measurements, Subject 2: 0900-1430	Estimated Time: (minutes)	Facility:	
1	Qualification	Ear exam/cleaning	20	Fitting room	-	-	-	
		Audiometric data	35	Auditory Assessment Chamber (AAC)	-	-	-	
	Pre-study Baselines	REAT training (attenuation)	45	Real Ear at Threshold (REAT)	-	-	-	
		Localization training	30	Auditory Localization Facility (ALF)	-	-	-	
		VOCRES training (comms)	45	Voice Communication Research & Evaluation System (VOCRES)	-	-	-	
	~3 hrs							
	2	Study	Open ear audiometric data	20	AAC	-	-	-
			Open ear REAT thresholds	20	REAT	-	-	-
			Device fitting	30	Fitting room	Open ear audiometric data	20	-
			Closed ear REAT thresholds	20	REAT	Open ear REAT thresholds	20	REAT
Occlusion & aided audiometric data			30	AAC	Device fitting	30	Fitting room	
Localization/detection			90	ALF	Closed ear REAT thresholds	20	REAT	
				Occlusion & aided threshold tests	30	AAC		
Communications (listener/talker conditions)			60	VOCRES	Communications (listener/talker conditions)	60	VOCRES	
BREAK			30	Break room	BREAK	30	Break room	
Closed ear REAT thresholds			20	REAT	Localization/detection	90	ALF	
Device removal			10	Fitting room	Closed ear REAT thresholds	20	REAT	
Open ear REAT thresholds			20	REAT	Device removal	10	Fitting room	
Questionnaires			15	AAC	Open ear REAT thresholds	20	REAT	
~6 hrs				Questionnaires	15	AAC		
				~6 hrs				

Preliminary Results on Two Pilot Subjects: Two pilot subjects who are investigators in the study were fitted with the Lyric devices, and preliminary measurements were completed for attenuation, hearing thresholds, localization accuracy and search time in an aurally guided visual search task.

Attenuation is measured for hearing protection devices using the standards developed by the American National Standards Institute (ANSI) published in 2008 and 2012, Methods for Measuring the Real-Ear Attenuation of Hearing Protectors, and Methods of Estimating Effective A-Weighted Sound Pressure Levels When Hearing Protectors Are Worn, respectively.



Figure 1: Real-Ear At Threshold Test Chamber, Air Force Research Laboratory

The Real-Ear Attenuation at Threshold (REAT) measurement is completed in a sound booth (Figure 1) using Bekesy audiometry. In Bekesy audiometry, the subject listens to 1/3rd octave-band noise from speakers and responds behaviorally by pressing a button when the noise is heard and releasing the button when the noise

is not heard. The hearing thresholds, gathered in this manner, for an open ear condition and a closed ear condition (hearing protector) result in the amount of attenuation for a given hearing protection device. Devices are measured with electronics “off” to measure the amount of passive protection (attenuation). Figures 2 and 3 demonstrate the attenuation for two pilot subjects (Subject A and B). Subject A received approximately 15-42 dB of attenuation across the frequency range tested, and Subject B received approximately 20- 40 dB of attenuation. For comparison, the Invisio V60 X5, tested at AFRL in May 2015, resulted in a mean attenuation of 25-44 dB across the frequency range tested, and the Aearo EAR Combat Arms Double-ended (brown end inserted) tested at AFRL in 2012 resulted in a mean attenuation of 22-41 dB. Based on the two pilot subjects, the Lyric device appears comparable to traditional hearing protection devices when used in the passive mode (off); however, further testing with the Lyric devices is needed to confirm these results. The results in Figures 1 and 2 show that, if needed, additional attenuation could be obtained by combining the Lyric with a second protector. In fact, it appears that it may be possible to achieve attenuation close to the bone conduction limit (traditional “double hearing protection” limit) simply by combining the Lyric devices with a second set of earplugs (Figure 2, Lyric with Earbuds and Earmuff condition). However, no additional attenuation is obtained by adding earmuffs to the “double hearing protection” condition of Lyric plus earbuds.

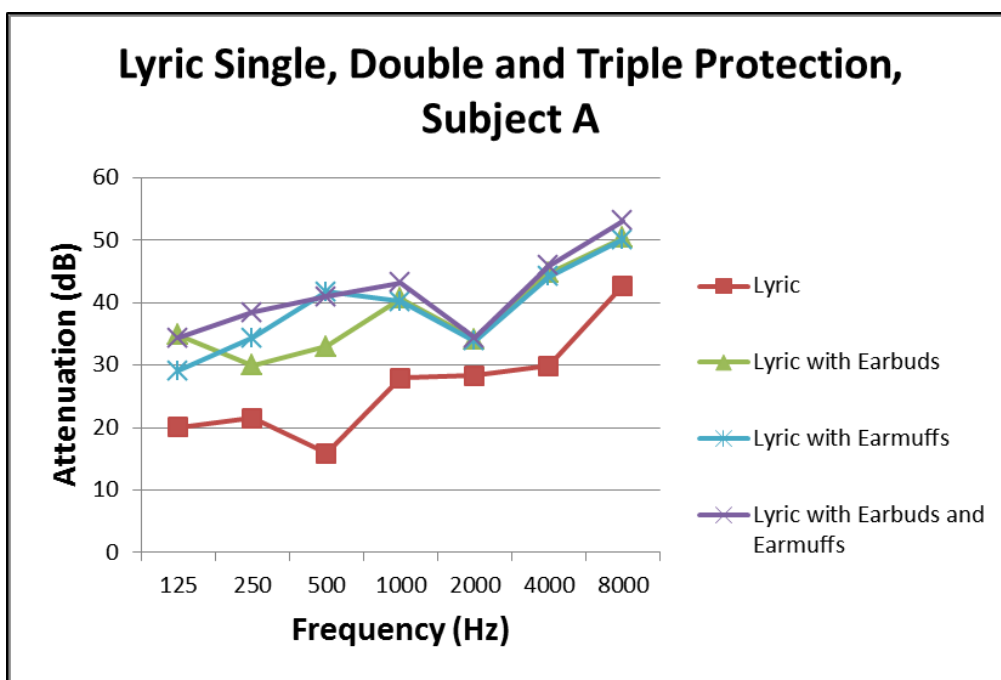


Figure 2: Attenuation with Lyric device, electronics off; pilot data on one subject (A), May 2015

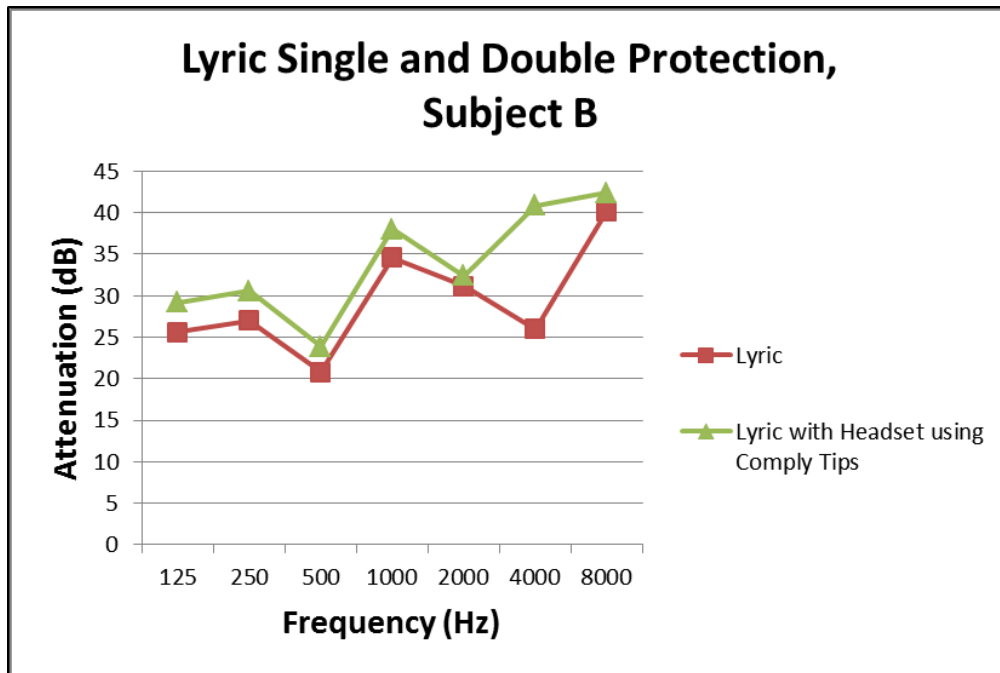


Figure 3: Attenuation with Lyric device, electronics off; pilot data on one subject (B), June 2015

Figures 3 to 6 demonstrate the hearing thresholds and aided hearing thresholds for the two pilot subjects. Both subjects have essentially normal hearing in both ears in the typical audiometric range (250 – 8000 Hz). The “sleep” mode provides approximately 10 dB less gain overall compared to the “on” mode. The prescribed gain with the Lyric device “on” shows that the device appears to allow the detection of 8-12 kHz when worn under headphones, suggesting that the device does pass through sufficient bandwidth to restore normal localization accuracy in normal hearing listeners.

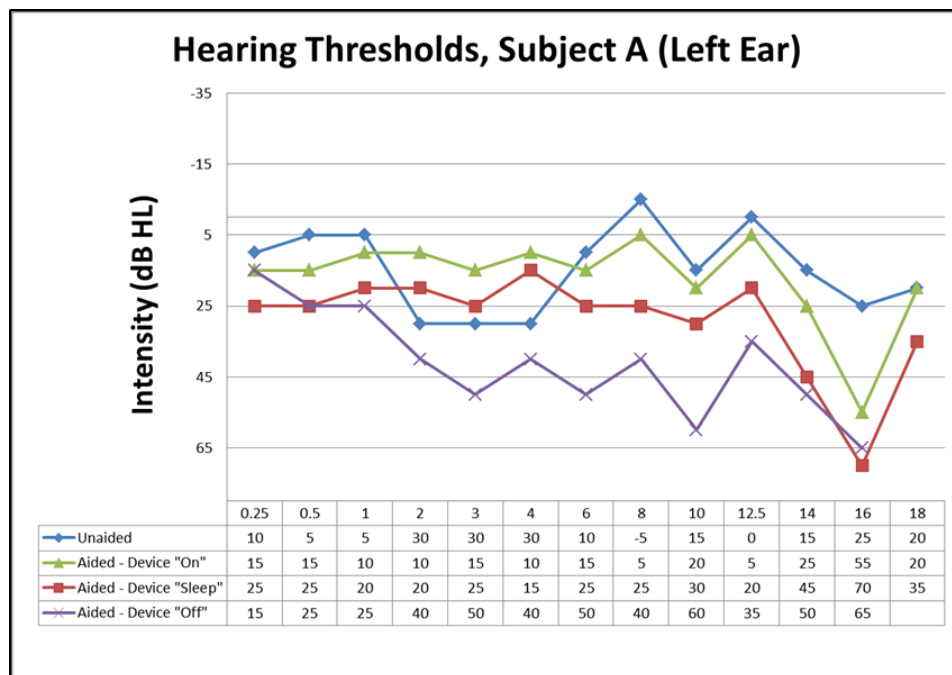


Figure 3: Audiometric thresholds with the Lyric device for pilot subject (A), left ear, tested May 2015

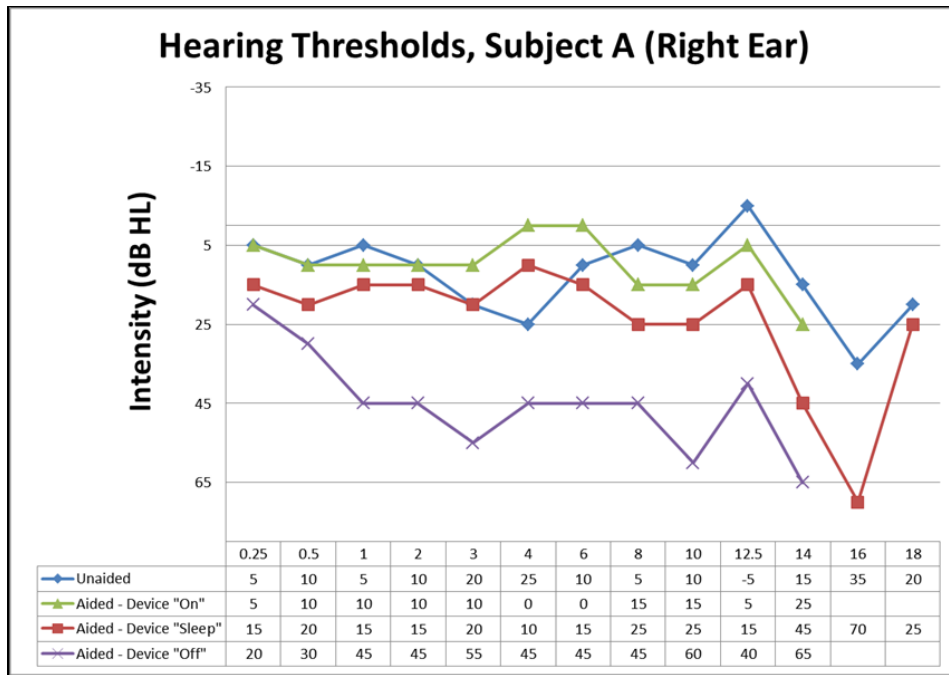


Figure 4: Audiometric thresholds with the Lyric device for pilot subject (A), right ear, May 2015

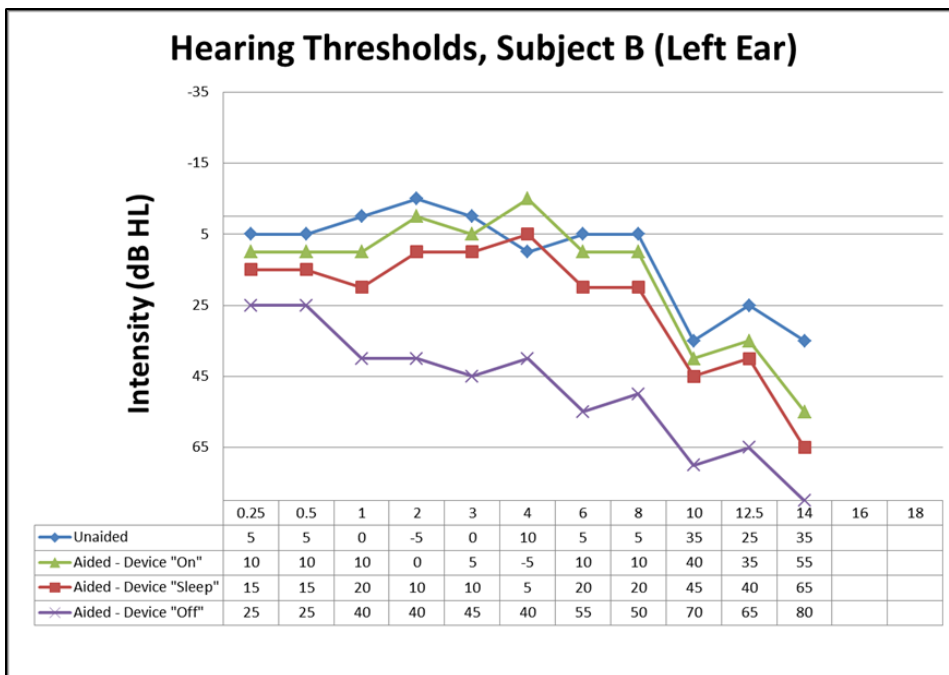


Figure 5: Audiometric thresholds with the Lyric device for pilot subject (B), left ear, June 2015

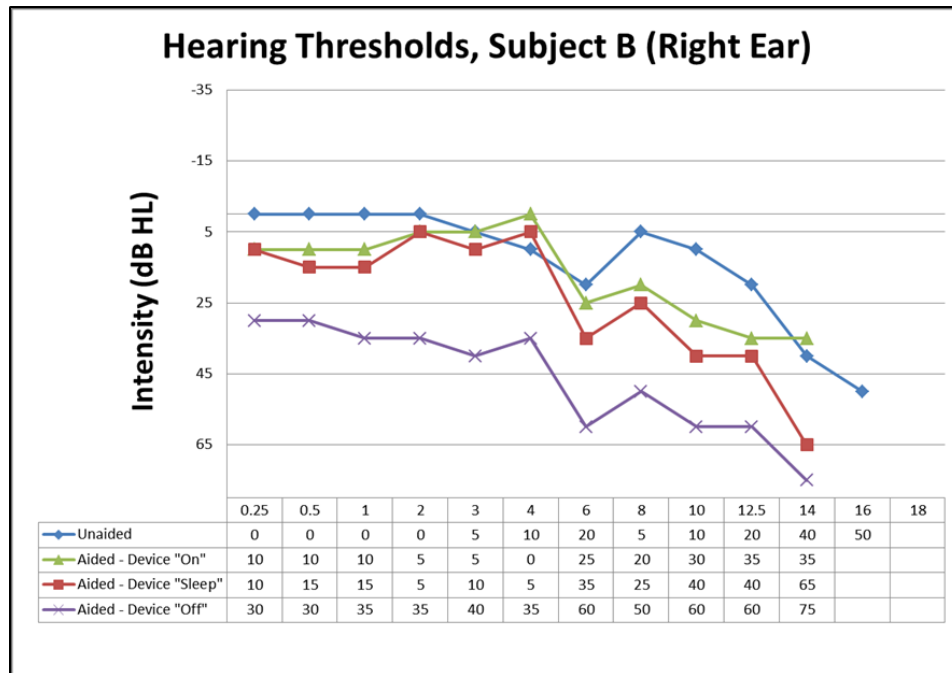


Figure 6: Audiometric thresholds with the Lyric device for pilot subject (B), right ear, June 2015

Localization errors and aurally guided visual search tasks were completed on two pilot subjects in the Auditory Localization Facility (ALF) (Figure 7) at AFRL. The aluminum-frame geodesic sphere is 14 feet in diameter with 4.5 inch loudspeakers. Four light-emitting diodes (LEDs) are located at each of the 277 vertices on its inside surface. The ALF apparatus is housed within an anechoic chamber. Subjects stand on a platform in the center of the sphere. Subjects use a head tracker to align his/her head to 0° azimuth, 0° elevation speaker location to begin each trial and use a wand with response buttons to point to the location of the sound source.

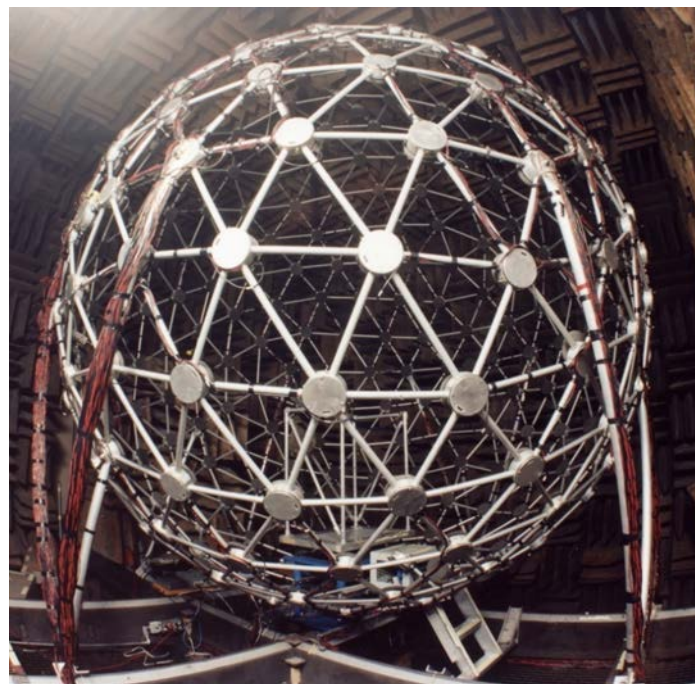


Figure 7: Auditory Localization Facility

When the pilot subject A wore the Lyric device in “on” mode, he was able to localize short duration (250 ms) sounds within 16 degrees and long duration (4s) sounds within 3 degrees; this is essentially equivalent to his localization ability without the devices in his ears (open ear). To our knowledge, this is the only active

listening device that has ever been shown to preserve normal localization accuracy in a test of this type. Performance in the “off” condition was very poor, presumably due to a loss of audibility at high frequencies. This degraded performance was partially restored when the stimulus level was increased from 65 dB to 80 dB, but even at 80 dB performance was significantly worse in the “off” condition than in either of the active conditions. For reference, the best existing active earplugs tend to generate errors in the range of 25-30 degrees for short duration sounds.

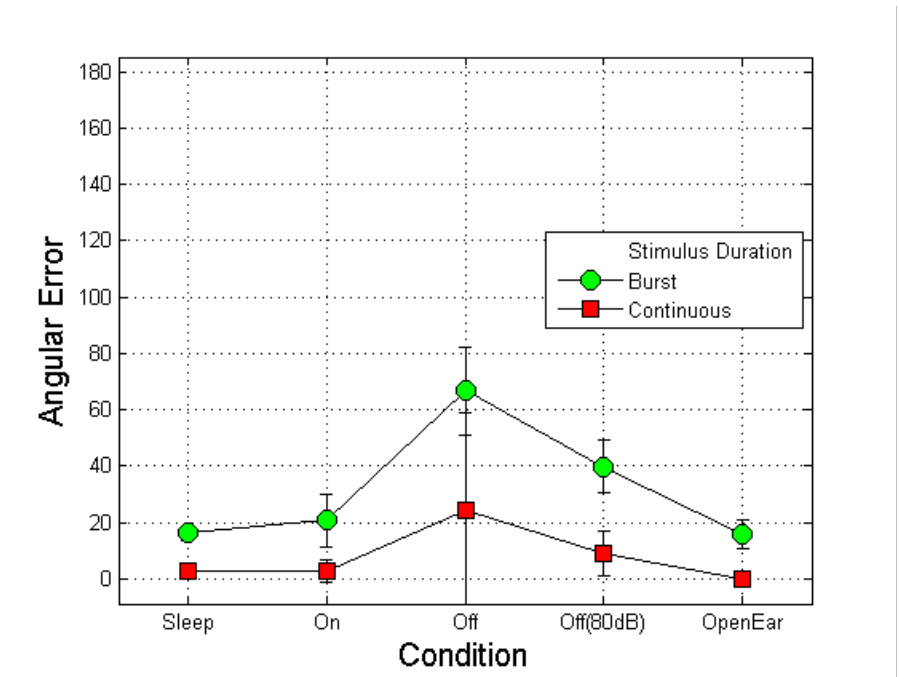


Figure 8: Auditory localization angular error; one pilot subject (A), May 2015

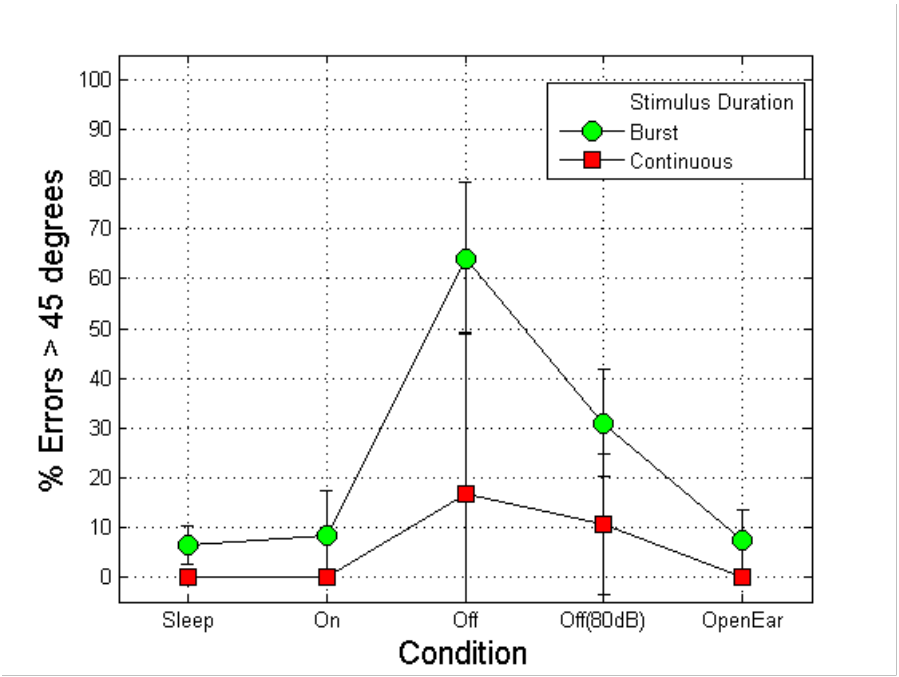


Figure 9: Auditory localization, > 45degree error percentage; one pilot subject (A), May 2015

For the aurally guided visual search task, response time to aurally locate and visually identify the sound source location was collected for one pilot subject (B). For this task, the target stimulus was a cluster of LEDs in which either two or four LEDs were illuminated. The distracter stimuli were clusters of LEDs with either

one or three illuminated LEDs. In addition, a 250 ms burst of broadband (200 Hz - 16 kHz) pink noise was played from the speaker at the target location at predetermined sound levels of 15, 25 and 40 dB SPL for aided and open ear conditions, and 40 and 70 dB SPL for aided-passive device condition. Results are shown in Figure 10. These results show that the “Lyric On” condition (blue filled stars) was comparable to the open-ear condition at all stimulus levels tested. In comparison, all of the other active protectors tested, including the current US Army TCAPs system (Invisio X50, red squares) resulted in a 2-4 fold increase in visual target acquisition time at 15 dB. At this highest signal level (70 dB), the Lyric in passive (off) mode (open stars) was close to open-ear performance, which was not true for any other protection device. While preliminary, these data suggest that the unique design of the Lyric, which uses an analog amplification circuit that preserves relatively high bandwidth and is inserted deeply in the ear canal where it minimizes the disruption of localization cues, could someday be used to produce a hearing protection system that preserves substantially more situational awareness than any other active or passive hearing protection system currently on the market.

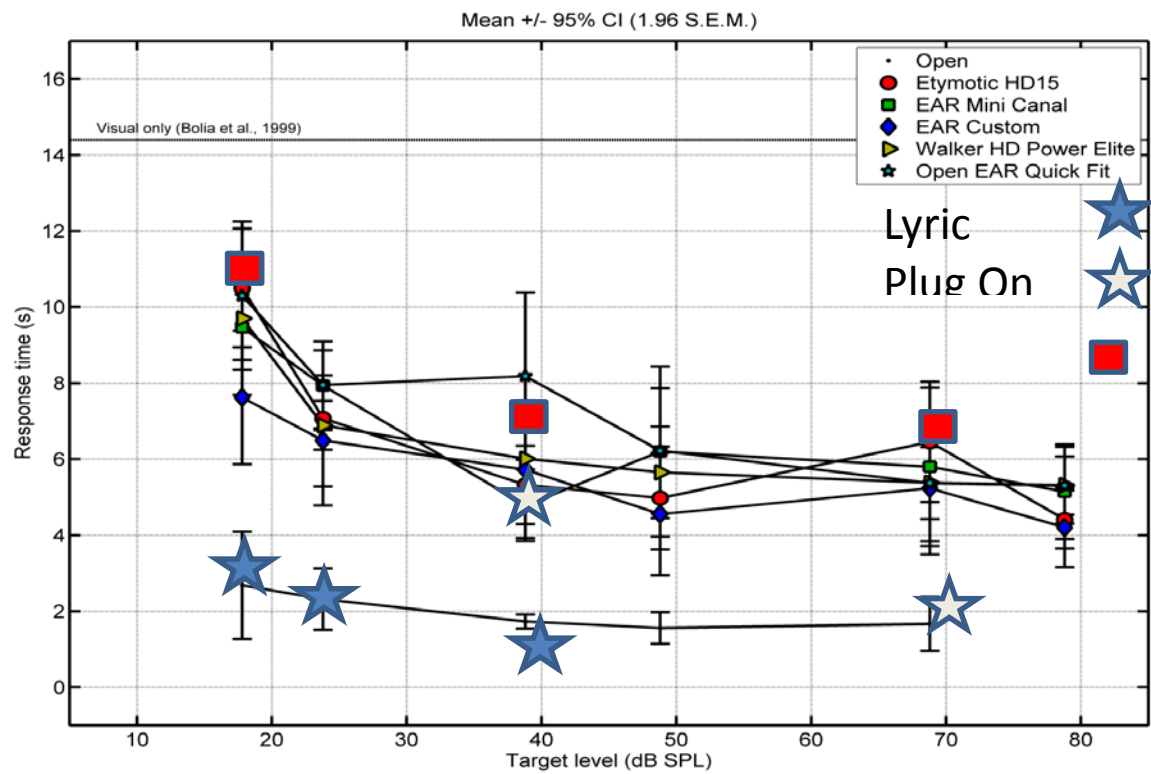


Figure 10: Aurally guided visual search task, one pilot subject (B), tested June 2015

What opportunities for training and professional development has the project provided?

The Lyric device is commercially available through Phonak, LLC. Phonak provides regional training audiologists who teach clinical fitting and considerations for the Lyric device. Training was provided at AFRL for several audiologists through Phonak’s regional consulting audiologist 26-28 May 2015. The training also provided the opportunity for researchers to meet face to face, finalize the test plan and collect preliminary pilot data.

How were the results disseminated to communities of interest? Nothing to report.

Impacts: Nothing to report

Changes/Problems: Nothing to report

Products: Nothing to report

Participants & Other Collaborating Organizations:

What individuals have worked on the project?

Name: Douglas Brungart
Project Role: Principal Investigator
Nearest person month worked: N/A
Contribution to Project: PI
Funding Support: Government employee

Name: Elizabeth McKenna
Project Role: Associate Investigator
Nearest person month worked: 7
Contribution to Project: AFRL lead researcher for project
Funding Support: Funded by award

Name: LaGuinn Sherlock
Project Role: Associate Investigator
Nearest person month worked: N/A
Contribution to Project: Consultation support
Funding Support: Government employee

Name: Ashley Zaleski
Project Role: Doctoral student
Nearest person month worked: N/A
Contribution to Project: Consultation support
Funding Support: Army Hearing Program

Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

Nothing to report.

What other organizations were involved as partners?

Organization Name: Integrated Demonstrations and Applications Laboratory, Electromagnetic Interference Research Laboratory, Wright-Patterson Air Force Base, OH
Partner's Contribution: Facilities and personnel exchanges; completed Electromagnetic Interference laboratory measurements on Lyric device prior to human testing in accordance with MIL-STD 461F.

Organization Name: Phonak, LLC
Partner's Contribution: In-kind support; provided on-site training, software and equipment for fitting of Lyric device.

Special Reporting Requirements: N/A

Appendices:

- 1) MIL-STD 461F Results for the Phonak, LLC, Lyric3 Hearing Aid, 28 April 2015.

28 April 2015

MIL-STD 461F Results for the Phonak, LLC, Lyric3 Hearing Aid

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1.0 EXECUTIVE SUMMARY

The Panasonic FZ-M1 was evaluated to the following requirements of MIL-STD-461F.

RE102 - Radiated Emissions, Electric Fields, 2 MHz to 18 GHz.

RS103 - Radiated Susceptibility, Electric Fields, 100 Volts/meter from 2 MHz to 1 GHz and 200 Volts/meter from 1 to 18 GHz.

1.1 Results Summary

RE102: The Lyric3 complies with the RE102 requirement for all Air Force aircraft including helicopters.

RS103: The Lyric3 passed all test requirements as stated above. The requirement for non-flight critical avionics is 20 V/m from 2 MHz to 1 GHz and 60 V/m from 1 GHz to 18 GHz, the flight critical requirement for the entire frequency range is 200 V/m.

2.0 GENERAL

2.1 Item Description

The equipment under test was a Lyric3 Hearing Aid, manufactured by Phonak, LLC. It is an extended wear hearing aid. Lyric's placement in the ear canal lets it deliver exceptional sound quality by working with the ear's natural anatomy. The outer ear naturally directs sound towards the Lyric hearing device, where sound is then amplified close to the ear drum. This improves directionality and localization (the ability to know where sounds are coming from), and reduces feedback. It also reduces background noise and helps improve the ability to hear high frequency sounds.

The hearing aid is shown below.



Lyric3 Hearing Aid, \approx 1.3 cm Long



Lyric3 Identification



Magnet used to Remotely Change Functions of Lyric3



G.R.A.S. 12Al 1-Channel CCP Power Module



G.R.A.S. High Frequency Audio Coupler

2.2 Facility

The measurements were performed in a 20 foot x 18 foot x 10 foot shielded room. The room is treated with anechoic material in accordance with MIL-STD-461F requirements. For RE102 and RS103, the measurements were under computer control in a control room adjacent to the main shielded room.

2.3 Modes of Operation

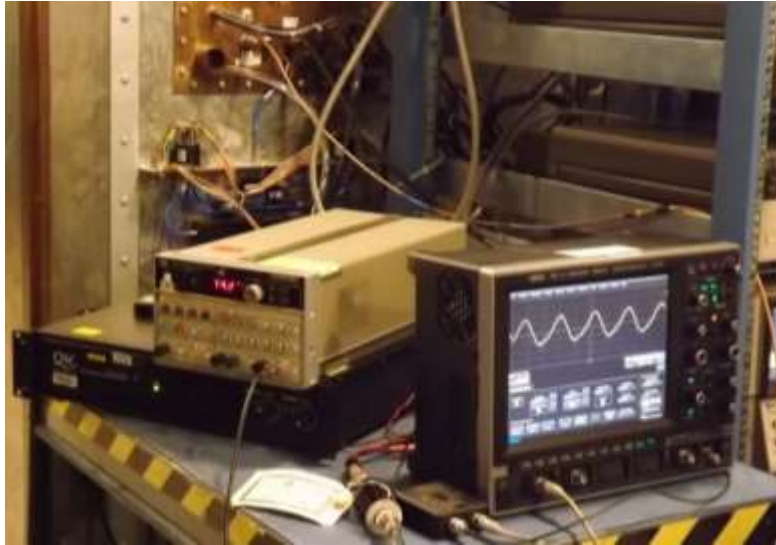
The Lyric3 was programmed for a linear gain response based on flat 50dB thresholds from 250-8000 Hz. The Lyric3 hearing aid was tested with a 500 Hz sinusoidal tone applied to the hearing aid during RE102 measurements. During RS103 testing from 120 MHz to 18 GHz a 450 Hz sinusoidal tone was applied to the hearing aid. The audio coupler was placed outside the test chamber at the end of a vinyl tube, 8 feet long with a 5/16" I.D. For this configuration the hearing aid was 15 cm above the ground plane. A second test configuration was accomplished from 2 MHz to 4 GHz using a 1500 Hz sinusoidal tone applied to the hearing aid. The audio coupler was placed 1/2" from the hearing aid and connected through a vinyl tube with a 5/16" I.D. For this configuration the hearing aid was 5 cm above the ground plane. The following testing was included since there were rumors of store security systems affecting the unit: frequency scans from 120 kHz to 140 kHz and 13 MHz to 14 MHz at 100 V/m, using a 1500 Hz sine, square and sawtooth waveforms.

2.4 General Setup

The general setup was as shown below for RE102 testing.



General Radiated Emissions Setup



Signal generator, audio amplifier and oscilloscope

During RS103 testing two configurations were used, one with an 8 foot vinyl, 5/16" I.D. tube between the hearing aid and the audio coupler and another with a 1/2" of tubing between the hearing aid and the audio coupler. A test was done comparing the pickup levels between these two configurations. The delta was 1.75 dB, implying that the tube acted as a waveguide with little loss. Additional photos are included in the individual test sections.

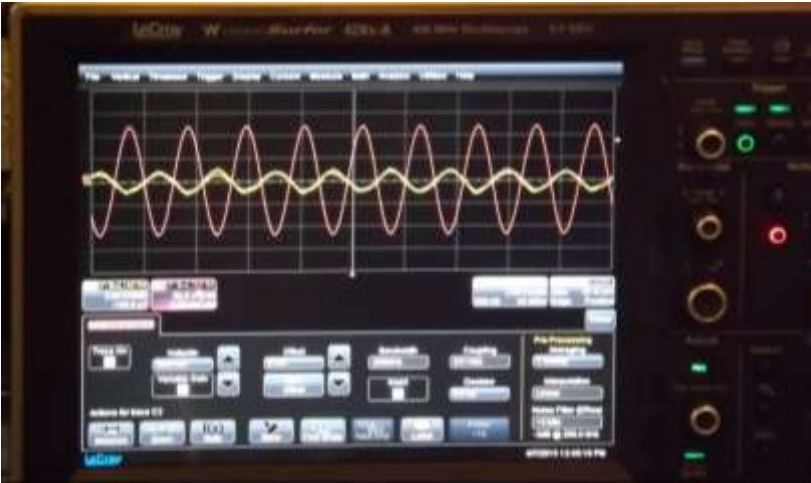


General Radiated Susceptibility Setup 1, 8'

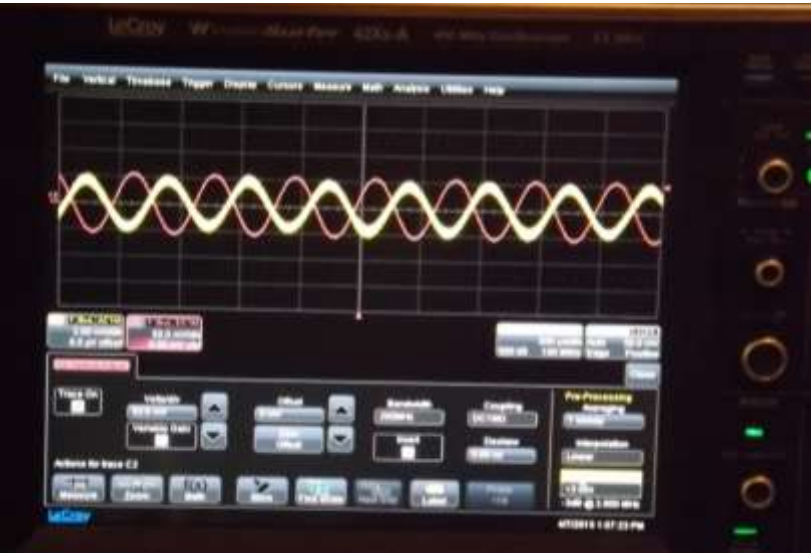


General Radiated Susceptibility Setup 2, 1/2"

The G.R.A.S. Power Module and Audio Coupler provided the output signal to the oscilloscope and the input and output waveforms were compared for distortion. See photos below



Montoring Input and OutputSignals



Montoring Input and OutputSignals

The two photos below show the signal generator drive level to the audio amplifier and the output of the G.R.A.S. Power Module and Audio Coupler. In the first photo the audio coupler is placed just before the hearing aid and in the second photo just after the hearing aid. These photos show a gain of roughly 8 dB.

Red - signal generator drive to amplifier and speaker
yellow - output of the power module with audio coupler



Audio Coupler placed just before Hearing Aid



Audio Coupler placed just after Hearing Aid



Drive speaker Incased in Foam

3.0 MEASUREMENTS PERFORMED

3.1 RE102 - Radiated Emissions, Electric Field, 2 MHz to 18 GHz

3.1.1 RE102 Measurement Conditions

The Lyric3 hearing aid and the measurement conditions were set up in accordance with MIL-STD-461F requirements. The instrumentation used is listed below.

RE102 Test Equipment

Manufacturer	Model	Function	Serial #	Cal Due Date
Hewlett Packard	8566B	Spectrum Analyzer	1925A00293/ 1928A00992	5/26/2015
Miteq	AFS42- 01001800-43- 10P-42-L	Preamplifier	1589785	NCR
ETS Lindgren	3301B	Rod Antenna	42919	NPC
EMCO	3109	Biconical Antenna	9603-2951	ICO
EMCO	3106	Double Ridge Guide Ant	2207	NPC
EMCO	3115	Double Ridge Guide Ant	2177	NCR
Hewlett Packard	8642B	Signal Generator	2816A02361	12/29/15
Hewlett Packard	8673E	Signal Generator	2821A00042	9/2/15

Calibration requirements and designations per the US Air Force Calibration Authority

NCR - No Calibration Required

NPC - No Periodic Calibration Required

ICO - Initial Calibration Only Required

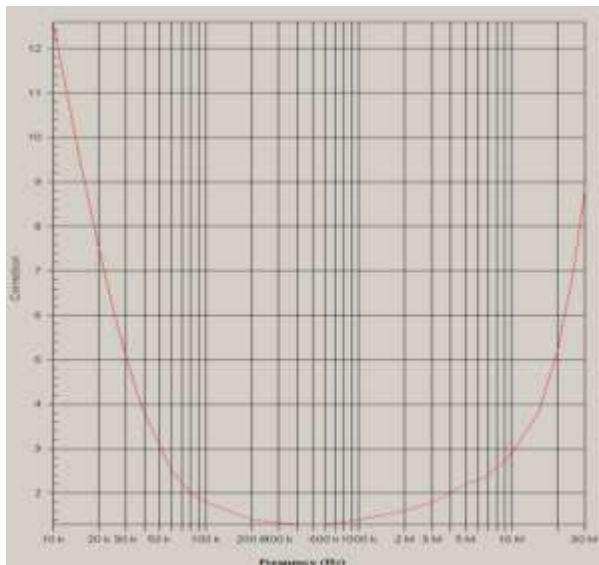
All antennas were positioned 1 meter from the EUT. Measurements above 30 MHz were performed in both vertical and horizontal antenna polarity positions. The bandwidths and sweep times used are listed below.

Bandwidths & Sweep Times

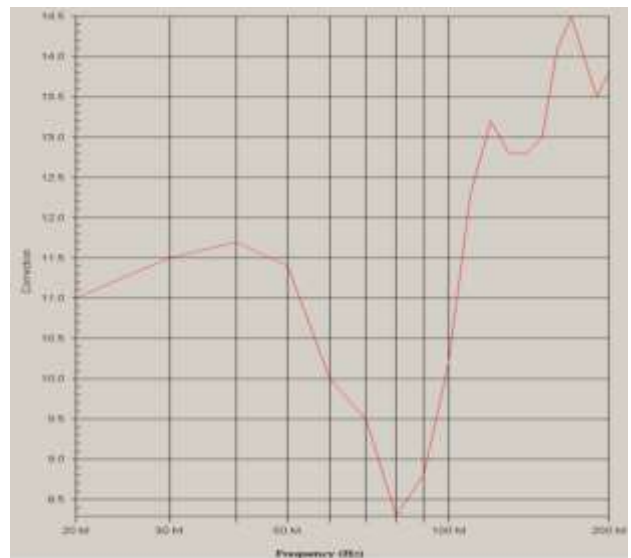
Frequency Band (MHz)	Resolution BW - 3 dB (kHz)	Video BW - 3 dB (kHz)	Sweep Times (Seconds)	Number of Sweeps
0.01 - 0.15	1	3	4	1
0.15 - 2	10	30	6	1
2 - 8	10	30	9	1
8 - 30	10	30	33	1
30 - 90	100	300	9	1
90 - 120	100	300	4.5	1
120 - 200	100	300	12	1

200 - 400	100	300	30	1
400 - 1000	100	300	90	1
1000 - 2000	1000	3000	15	1
2000 - 4000	1000	3000	30	1
4000 - 8000	1000	3000	60	1
8000 - 12000	1000	3000	60	1
12000 - 18000	1000	3000	90	1

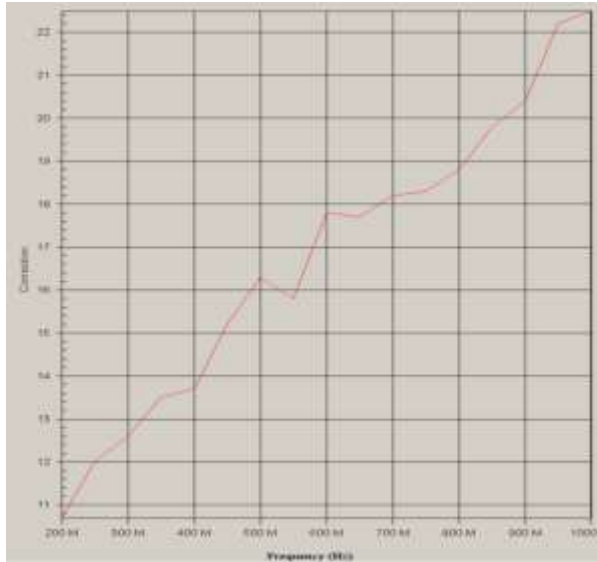
Commercial software is used for testing. The program is Dare Development's RadiMation package, Version 5.8.16. The antennas factors for the measurement antennas as stored in the software are shown below.



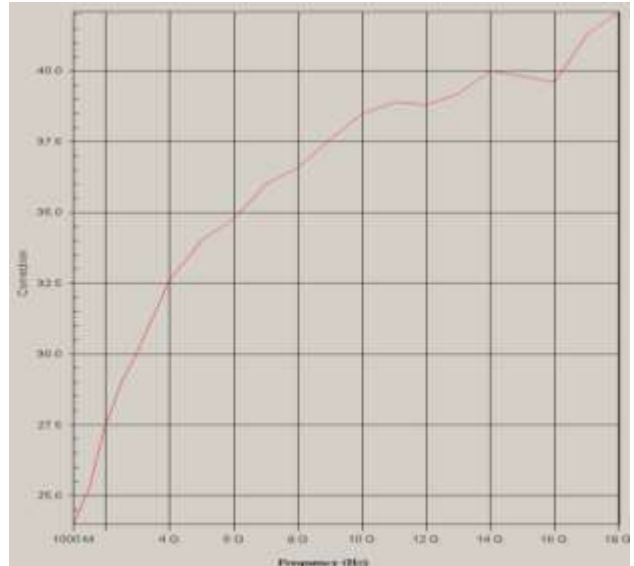
EMCO 3301B Monopole



EMCO 3109 Biconical

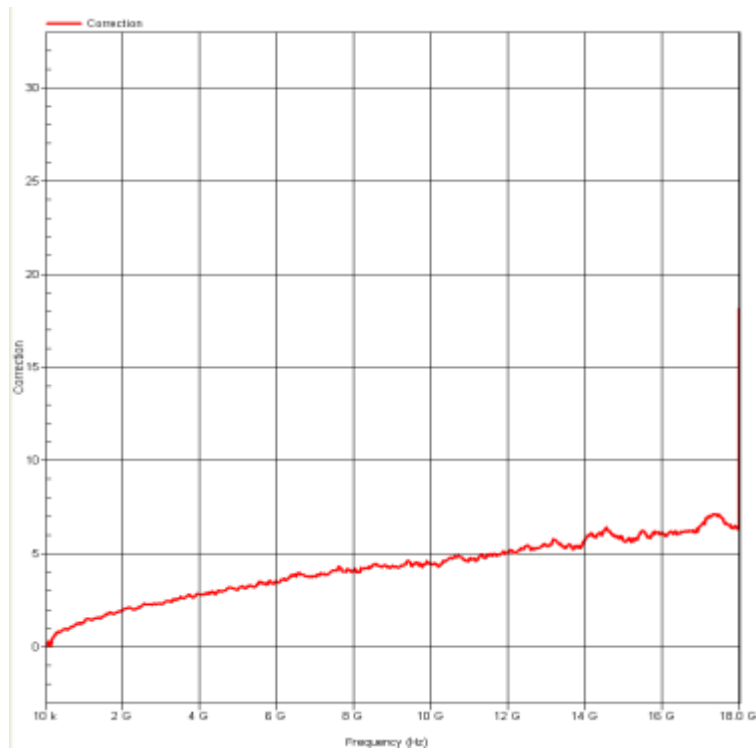


EMCO 3106 Double Ridge Guide



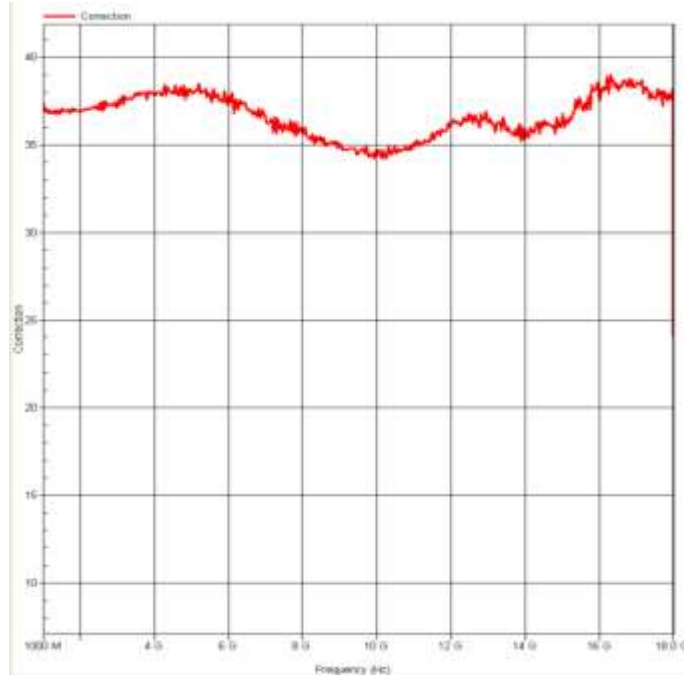
EMCO 3115 Double Ridge Guide

The cable loss from the antenna to the measurement receiver as stored in the software is shown below. The loss was measured using a signal source and power meter. A reference level was first established on the power meter at each frequency. The entire cable was then inserted and the power level again measured. The difference is the cable loss.



Total Path Loss

A preamplifier is used between 1 and 18 GHz to improve the sensitivity of the measurement system. The gain as stored in the software is shown below.



Miteq 1589785 Gain, 1 to 18 GHz

Information used to determine the drive level for system accuracy scans is shown below. The limit that is used is for RE102 small-fixed wing, aircraft applications. Injected levels in dBm are calculated as follows:

Frequency (MHz)	A	B = A - 6	C	D = B - C	E = D - 107	Remarks
	Limit (dBuV/m)	Limit less 6 dB (dBuV/m)	Antenna Factor (dB/m)	Injected Level (dBuV)	Injected Level (dBm)	
2.1	34.0	28.0	6	22.0	-85	Antenna factor for signal injection purposes is 1/2 m height of rod
12	34.0	28.0	6	22.0	-85	Antenna factor for signal injection purposes is 1/2 m height of rod
29.5	34.0	28.0	6	22.0	-85	Antenna factor for signal injection purposes is 1/2 m height of rod
197	39.9	33.9	13.8	20.1	-86.9	
990	53.9	47.9	22.4	25.5	-81.5	
1950	59.8	53.8	27.3	26.5	-80.5	
17500	78.9	72.9	41.7	31.2	-75.8	

Photos of the test setups are shown below.



Rod Antenna, 10 kHz to 30 MHz



Vertical Polarization

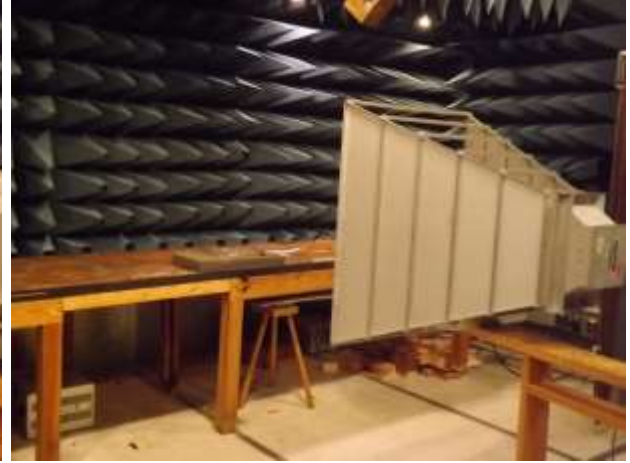


Horizontal Polarization

Biconical Antenna, 30 to 200 MHz

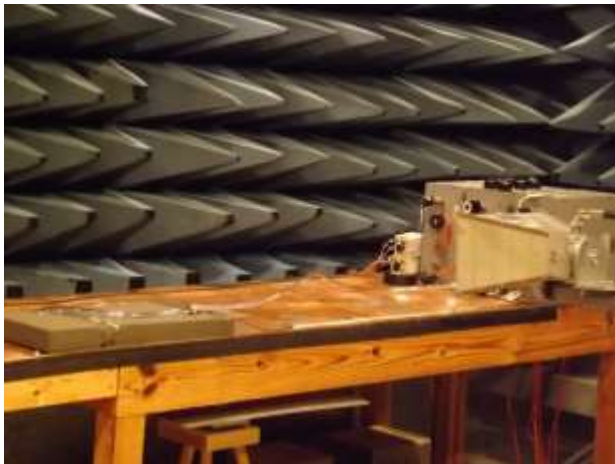


Vertical Polarization

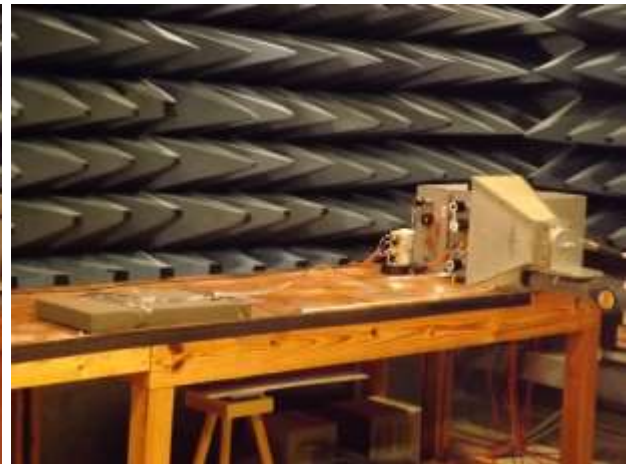


Horizontal Polarization

Double Ridge Guide Antenna, 200 to 1000 MHz



Vertical Polarization



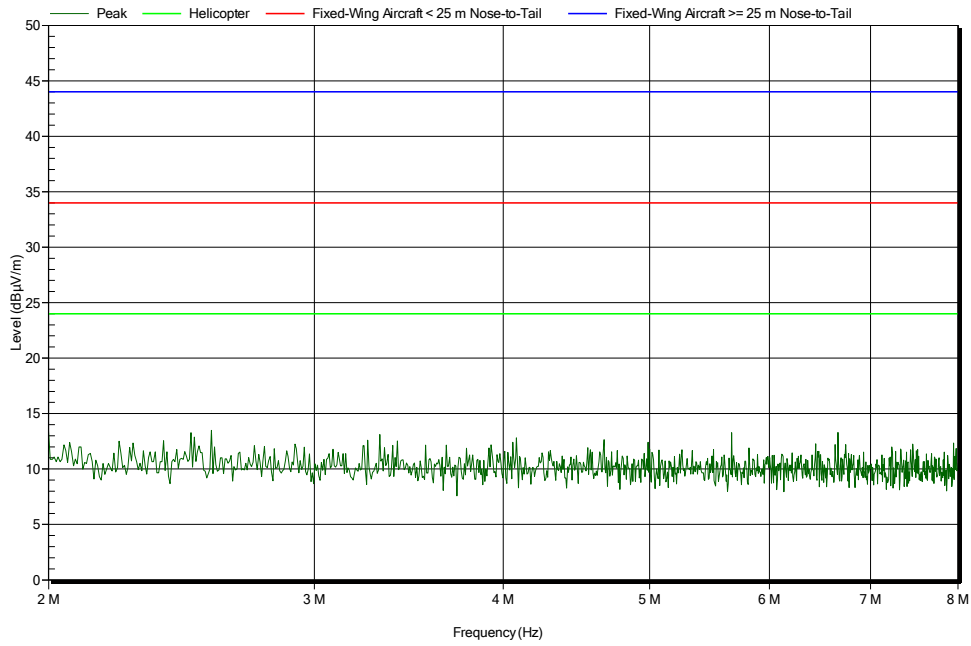
Horizontal Polarization

Double Ridge Guide Antenna, 1 to 18 GHz

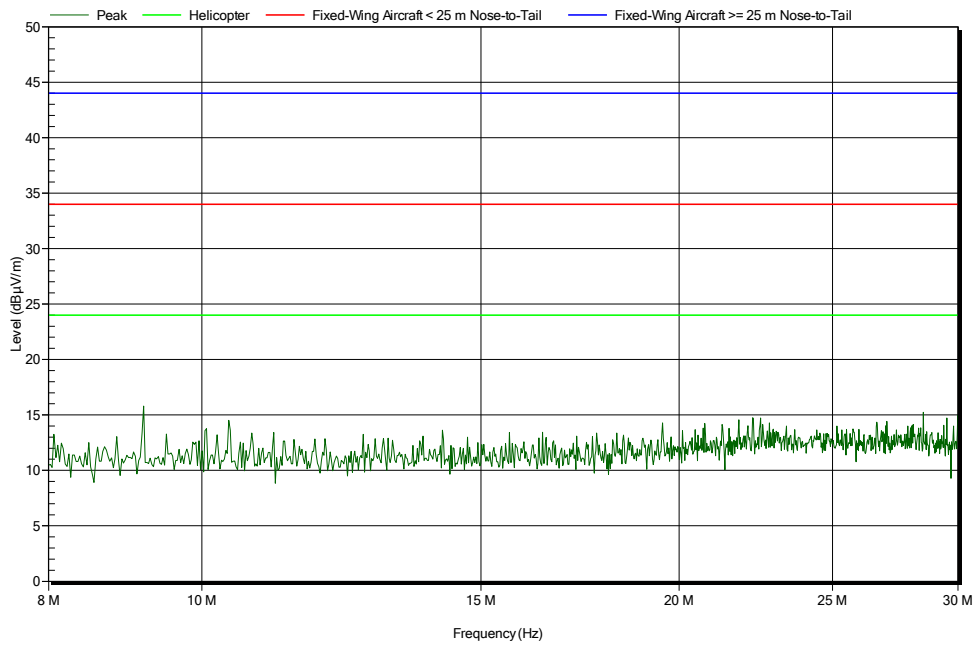
3.1.2 RE102 Results

3.1.2.1 RE102 EUT Measurement Scans

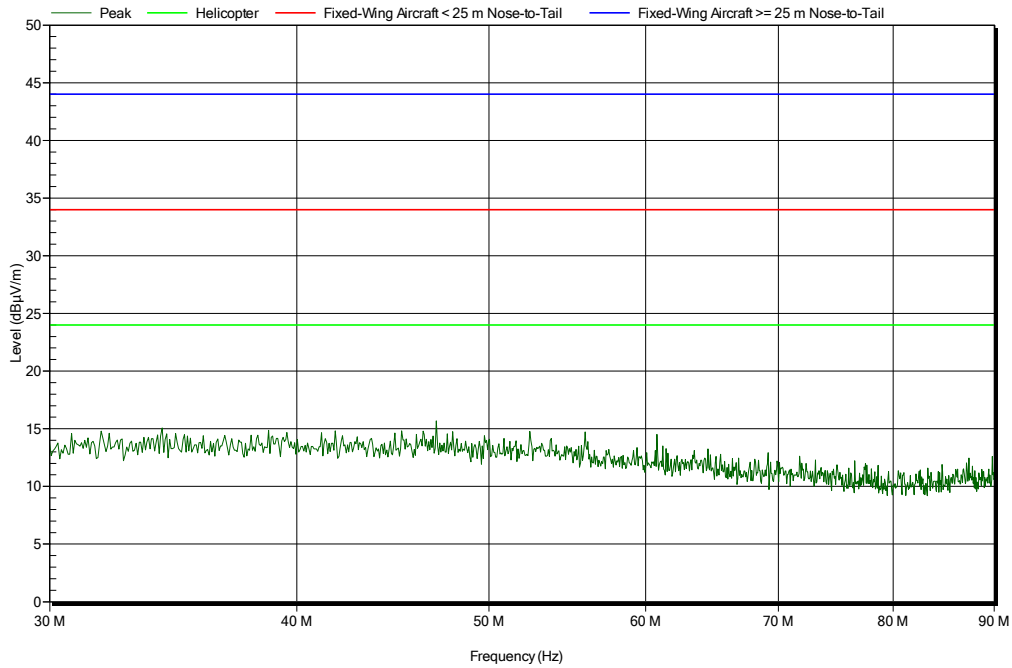
RE102: 2 - 8 MHz. Lyric3 hearing aid. Time of Measurement: 4/6/2015 10:23:08 AM



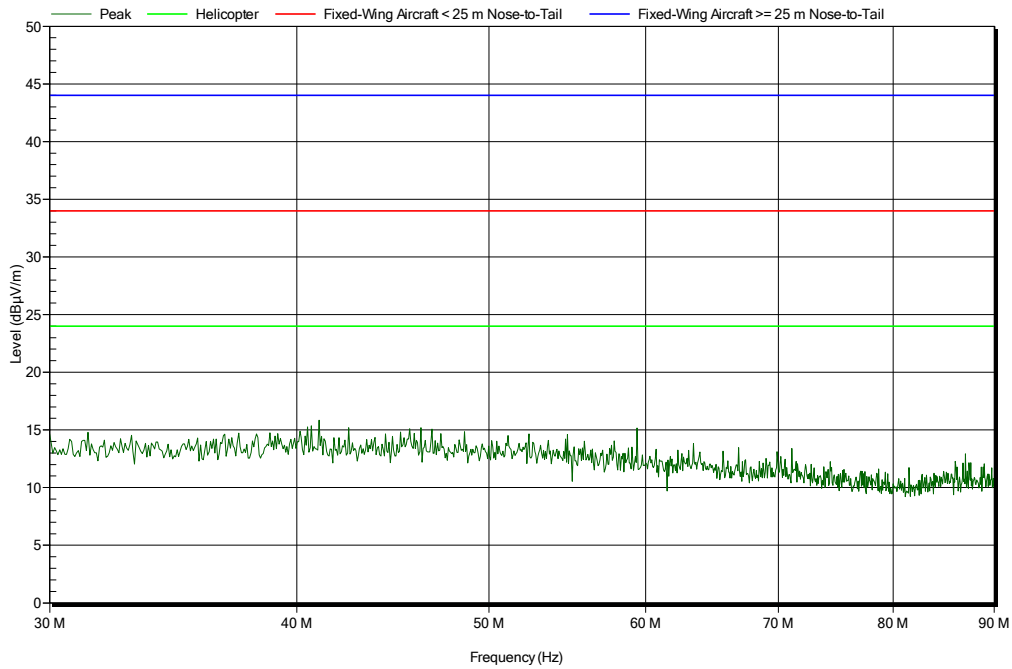
RE102: 8 - 30 MHz. Lyric3 hearing aid. Time of Measurement: 4/6/2015 10:24:43 AM



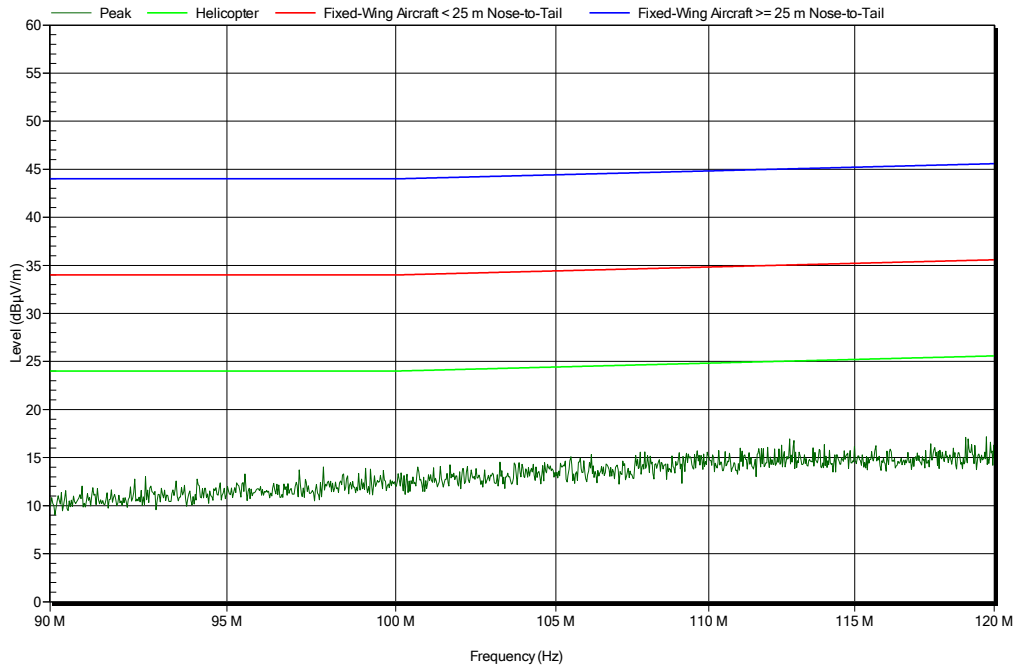
RE102: 30 - 90 MHz. Antenna polarity: Vertical. Lyric3 hearing aid. Time of Measurement: 4/6/2015 10:42:58 AM



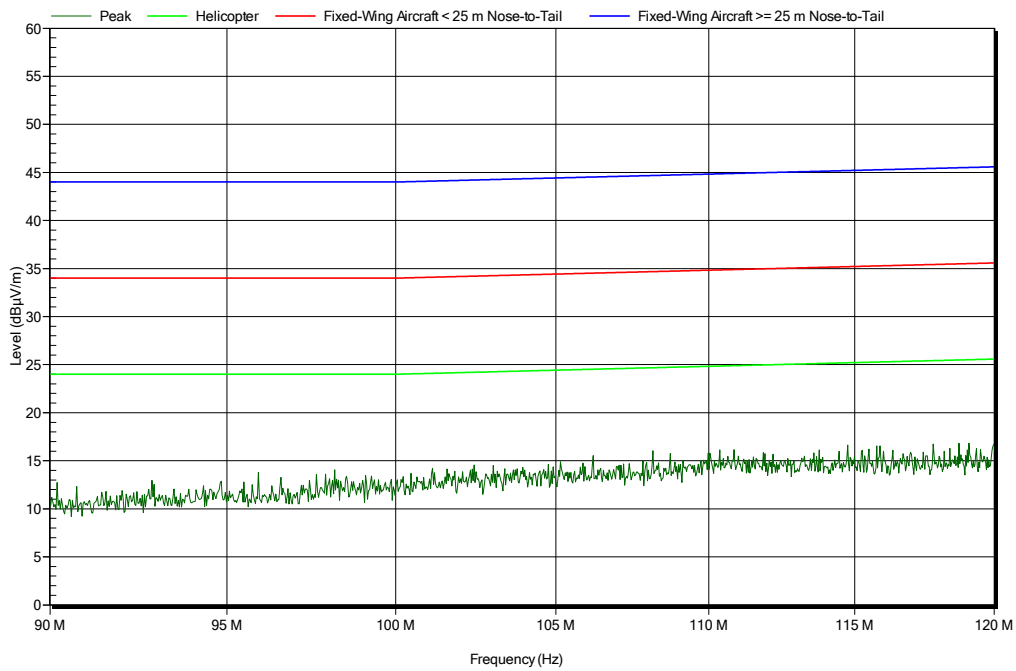
RE102: 30 - 90 MHz. Antenna polarity: Horizontal. Lyric3 hearing aid. Time of Measurement: 4/6/2015 10:35:16 AM



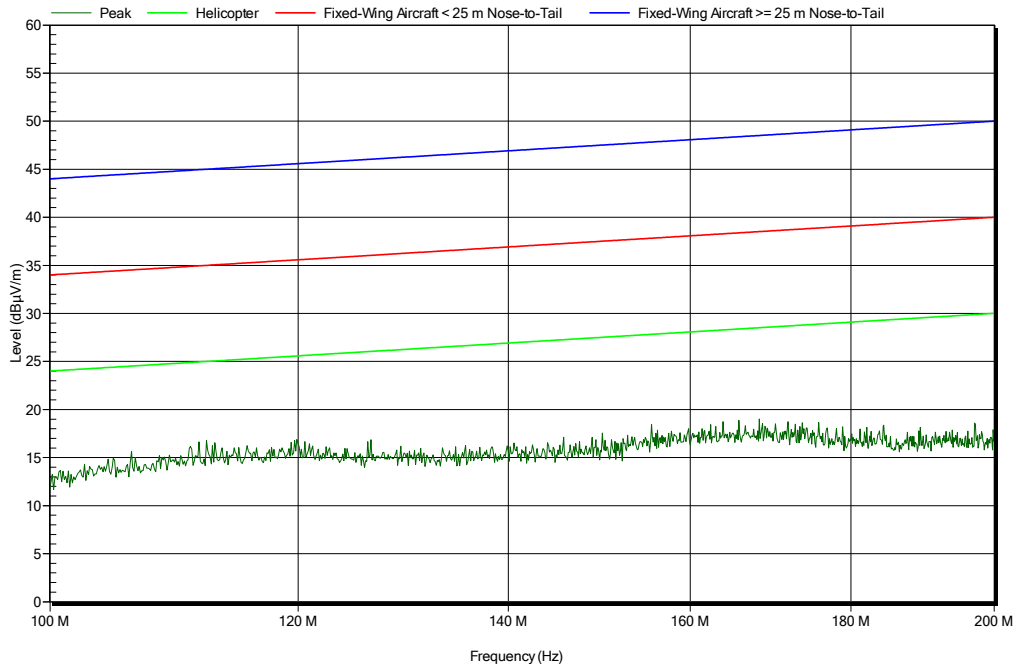
RE102: 90 - 120 MHz. Antenna polarity: Vertical. Lyric3 hearing aid. Time of Measurement: 4/6/2015 10:43:51 AM



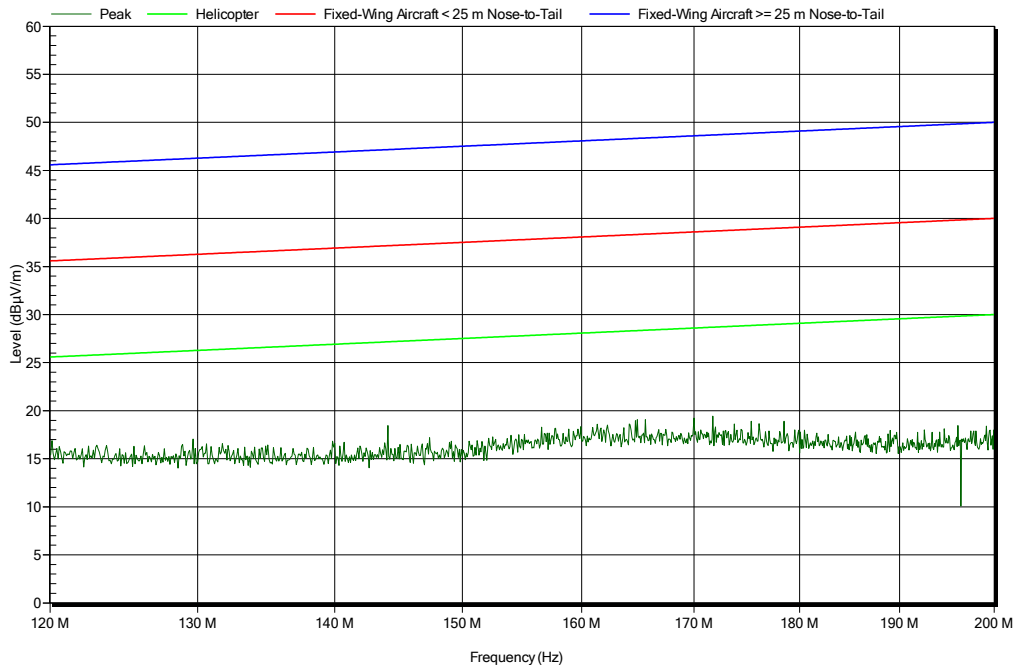
RE102: 90 - 120 MHz. Antenna polarity: Horizontal. Lyric3 hearing aid. Time of Measurement: 4/6/2015 10:36:27 AM



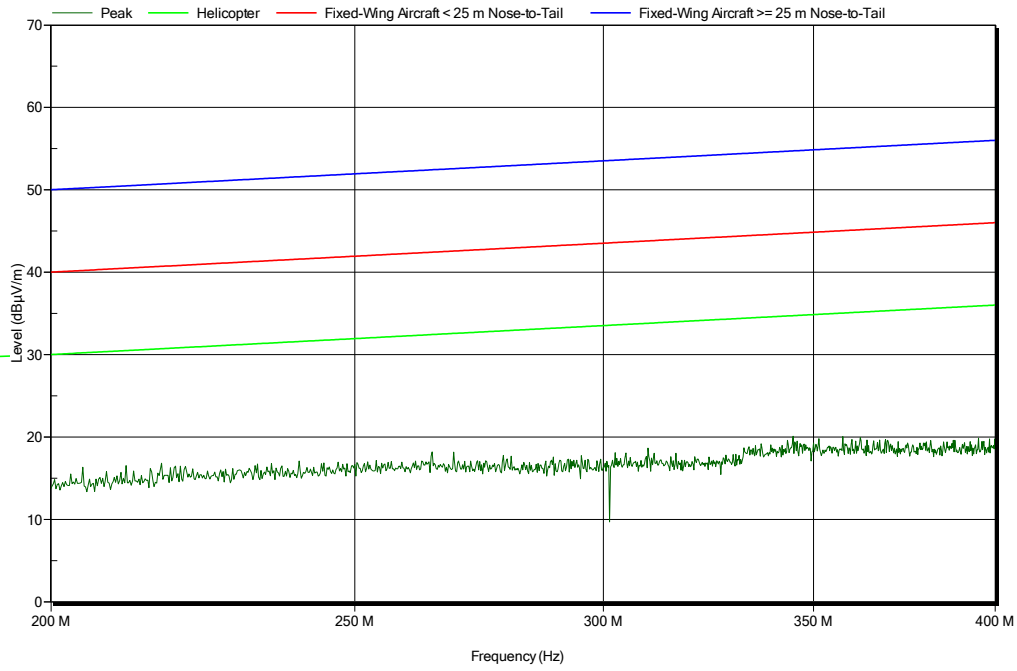
RE102: 120 - 200 MHz. Antenna polarity: Vertical. Lyric3 hearing aid. Time of Measurement: 4/6/2015 10:45:05 AM



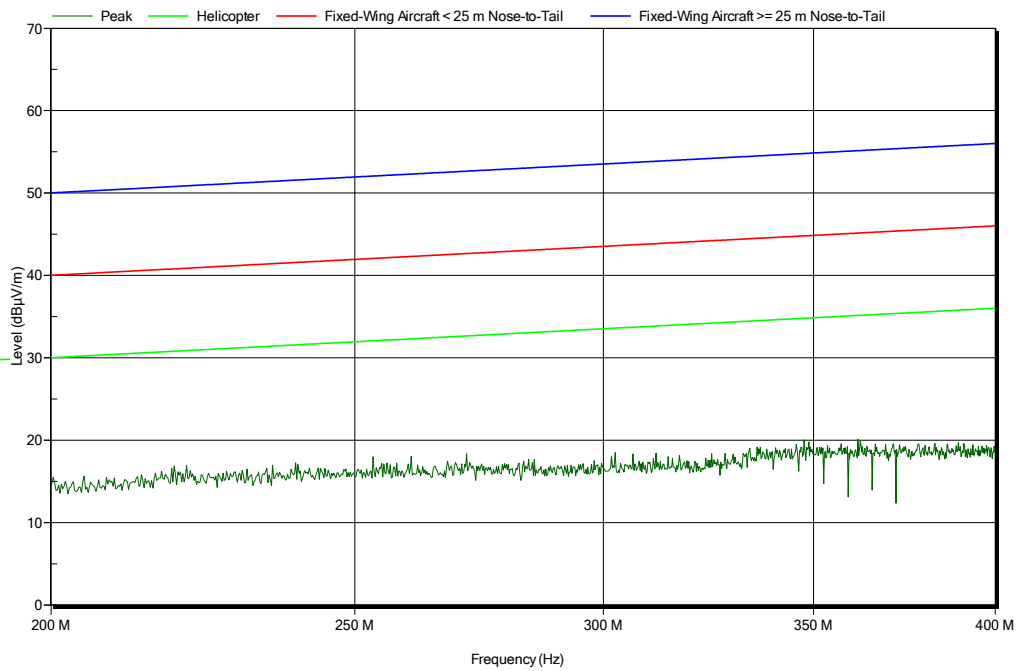
RE102: 120 - 200 MHz. Antenna polarity: Horizontal. Lyric3 hearing aid. Time of Measurement: 4/6/2015 10:37:29 AM



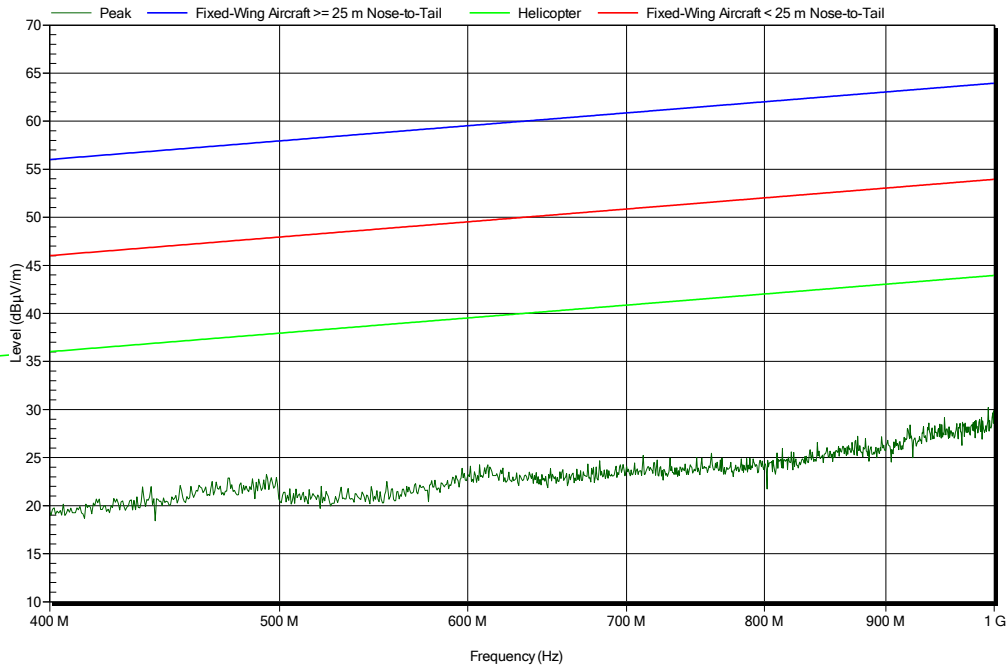
RE102: 200 - 400 MHz. Antenna polarity: Vertical. Lyric3 hearing aid. Time of Measurement: 4/6/2015 11:09:03 AM



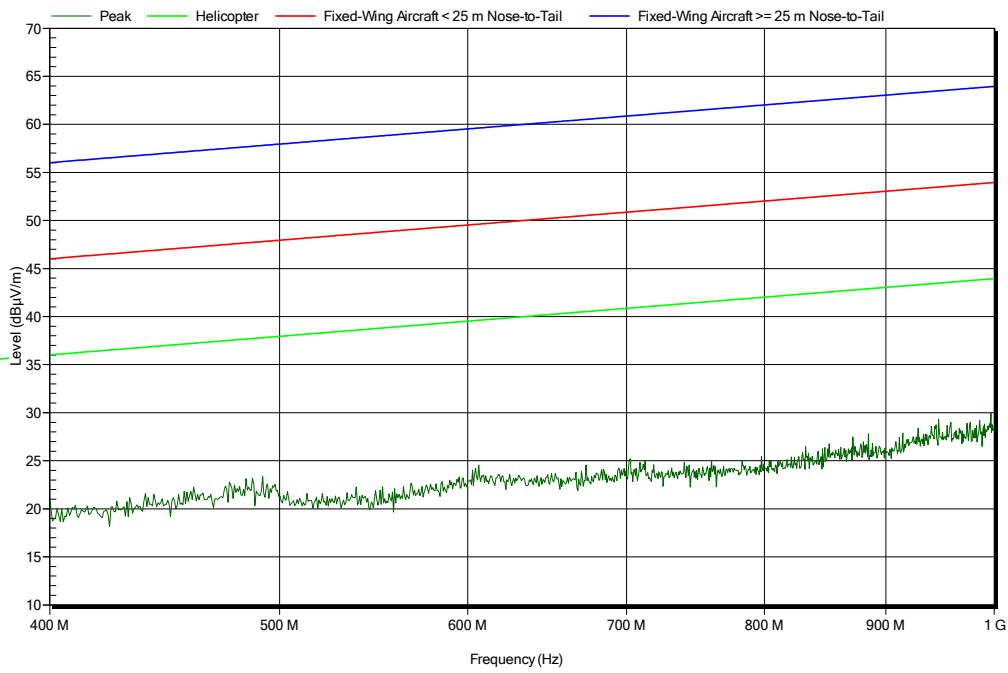
RE102: 200 - 400 MHz. Antenna polarity: Horizontal. Lyric3 hearing aid. Time of Measurement: 4/6/2015 11:22:03 AM



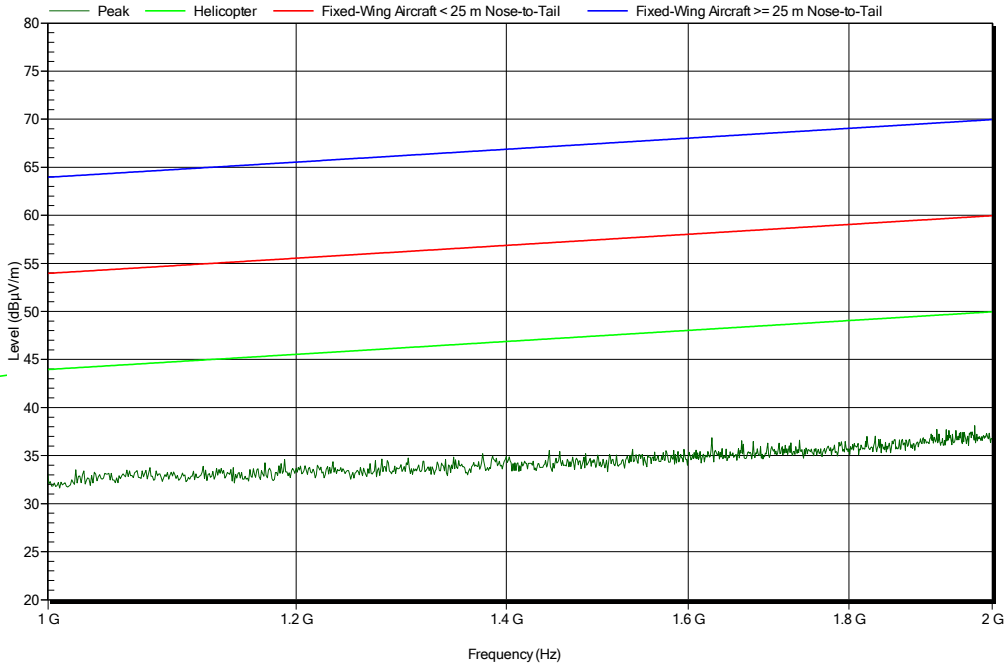
RE102: 400 - 1000 MHz. Antenna polarity: Vertical. Lyric3 hearing aid. Time of Measurement: 4/6/2015 11:14:18 AM



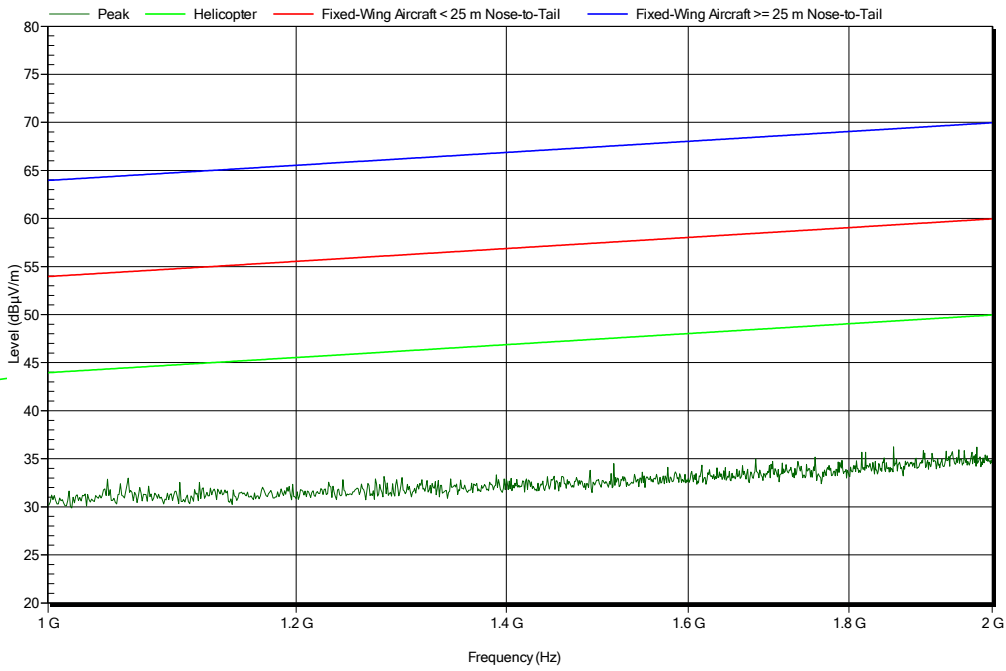
RE102: 400 - 1000 MHz. Antenna polarity: Horizontal. Lyric3 hearing aid. Time of Measurement: 4/6/2015 11:24:18 AM



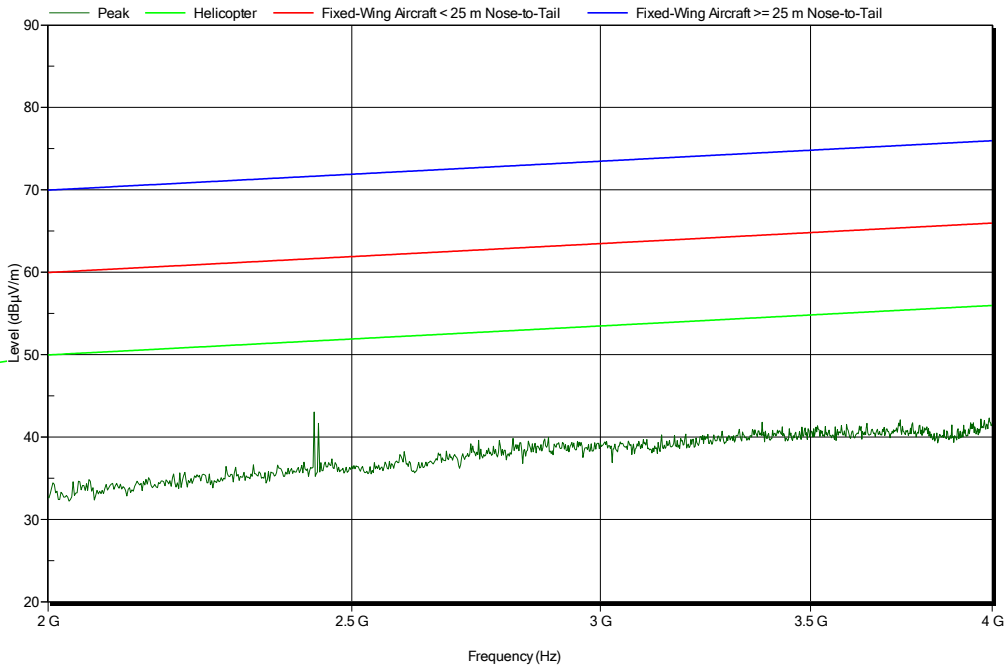
RE102: 1 - 2 GHz. Antenna polarity: Vertical. Lyric3 hearing aid. Time of Measurement: 4/6/2015 12:16:52 PM



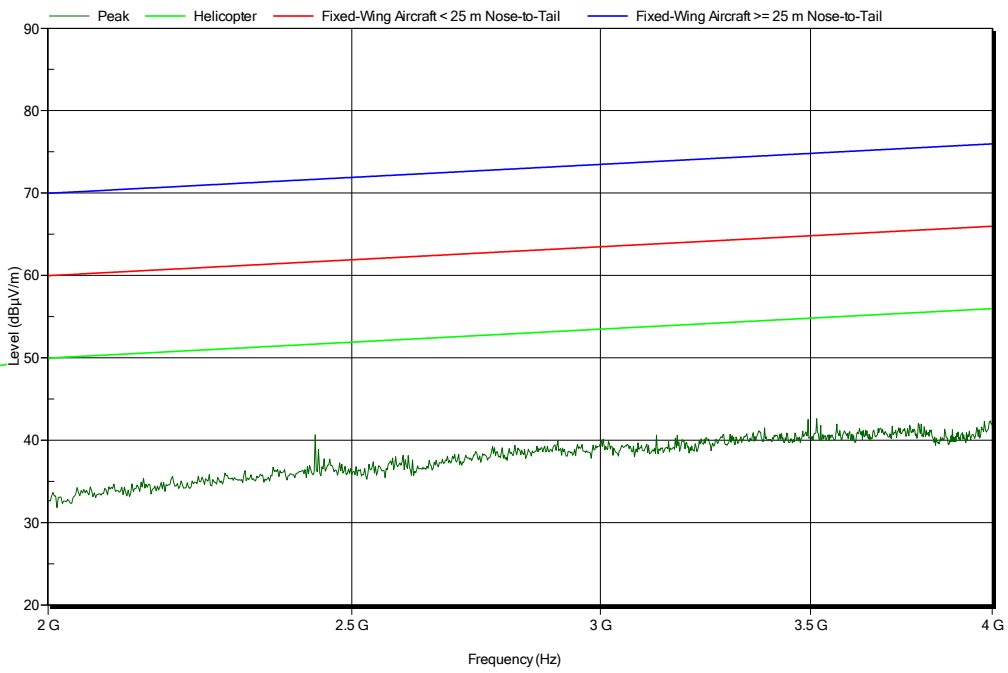
RE102: 1 - 2 GHz. Antenna polarity: Horizontal. Lyric3 hearing aid. Time of Measurement: 4/6/2015 11:54:30 AM



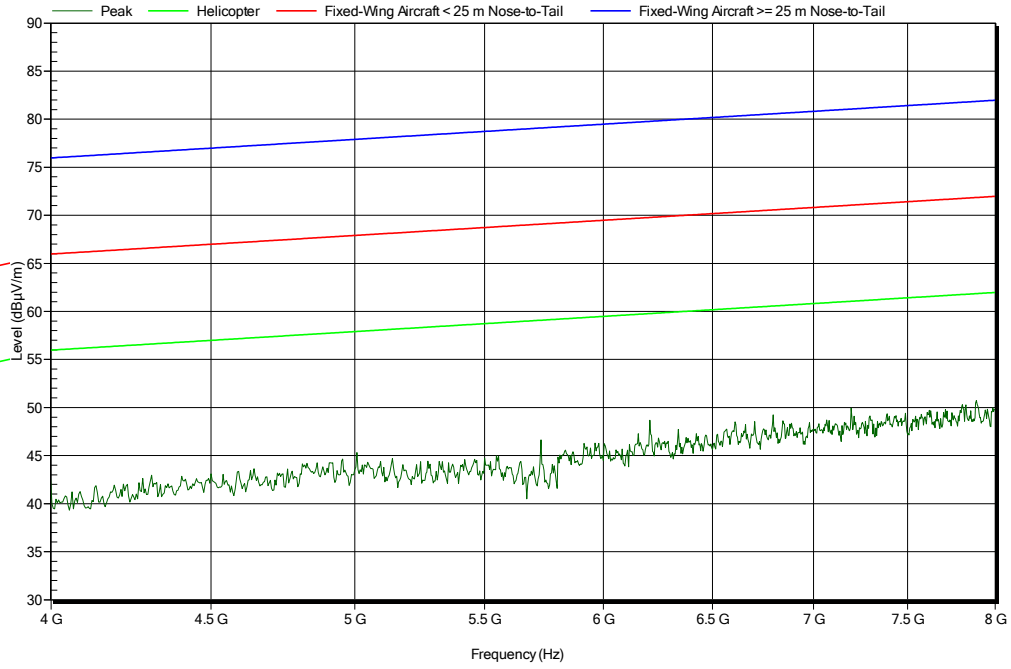
RE102: 2 - 4 GHz. Antenna polarity: Vertical. Lyric3 hearing aid. Time of Measurement: 4/6/2015 12:18:22 PM



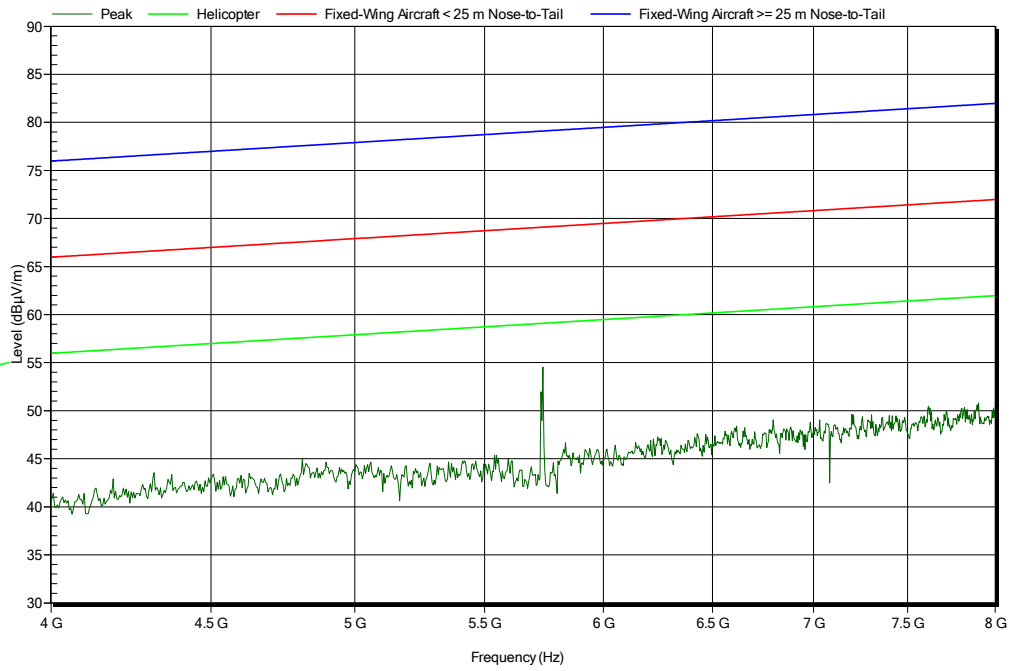
RE102: 2 - 4 GHz. Antenna polarity: Horizontal. Lyric3 hearing aid. Time of Measurement: 4/6/2015 11:56:07 AM



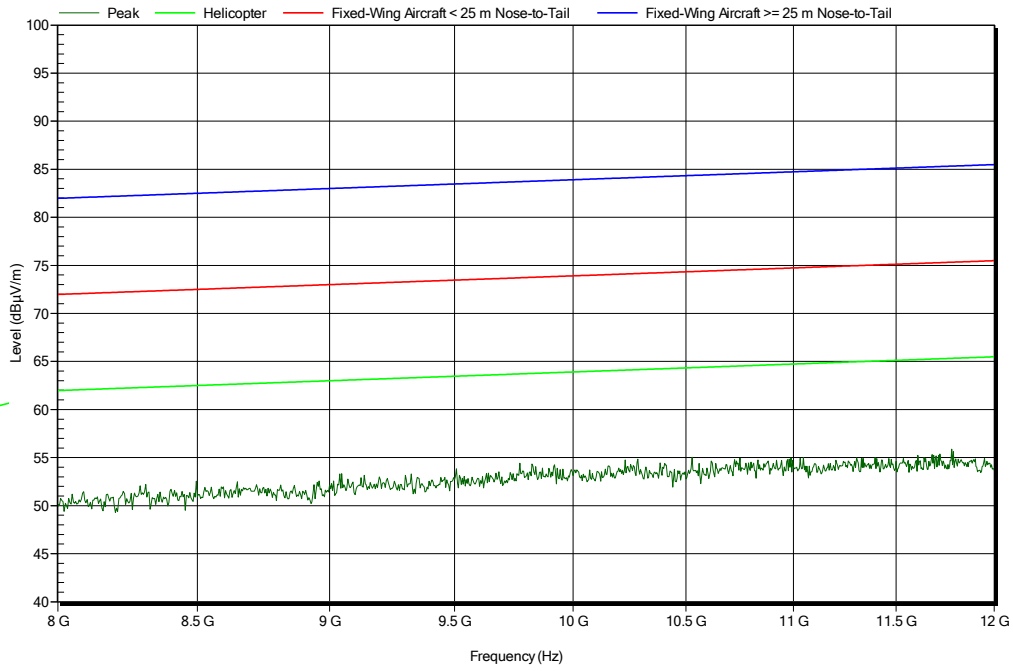
RE102: 4 - 8 GHz. Antenna polarity: Vertical. Lyric3 hearing aid. Time of Measurement: 4/6/2015 12:21:01 PM



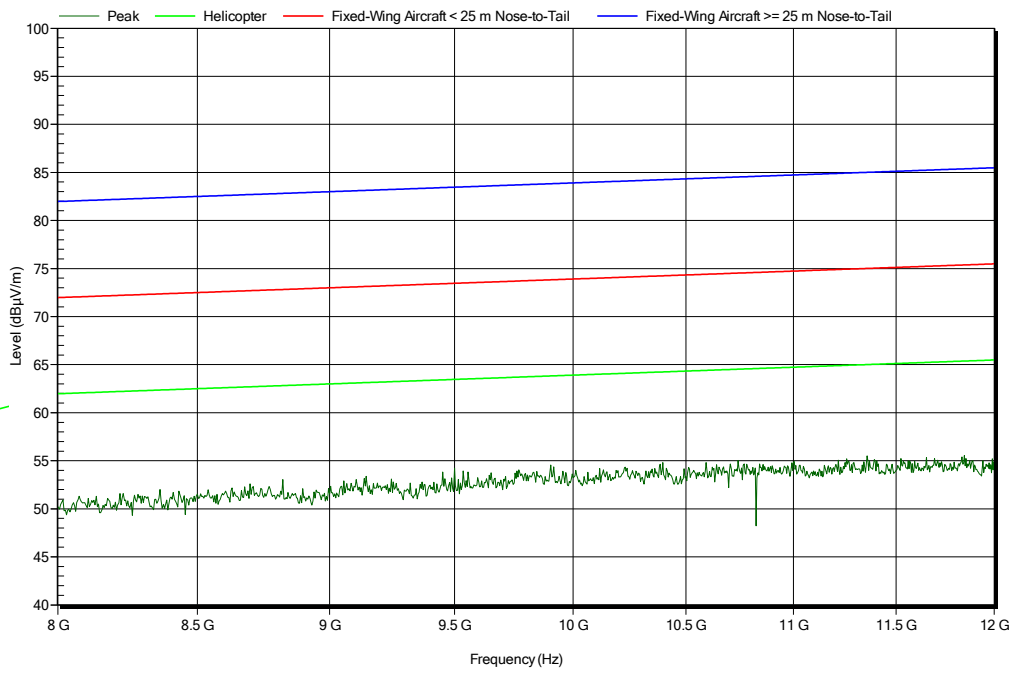
RE102: 4 - 8 GHz. Antenna polarity: Horizontal. Lyric3 hearing aid. Time of Measurement: 4/6/2015 11:57:41 AM



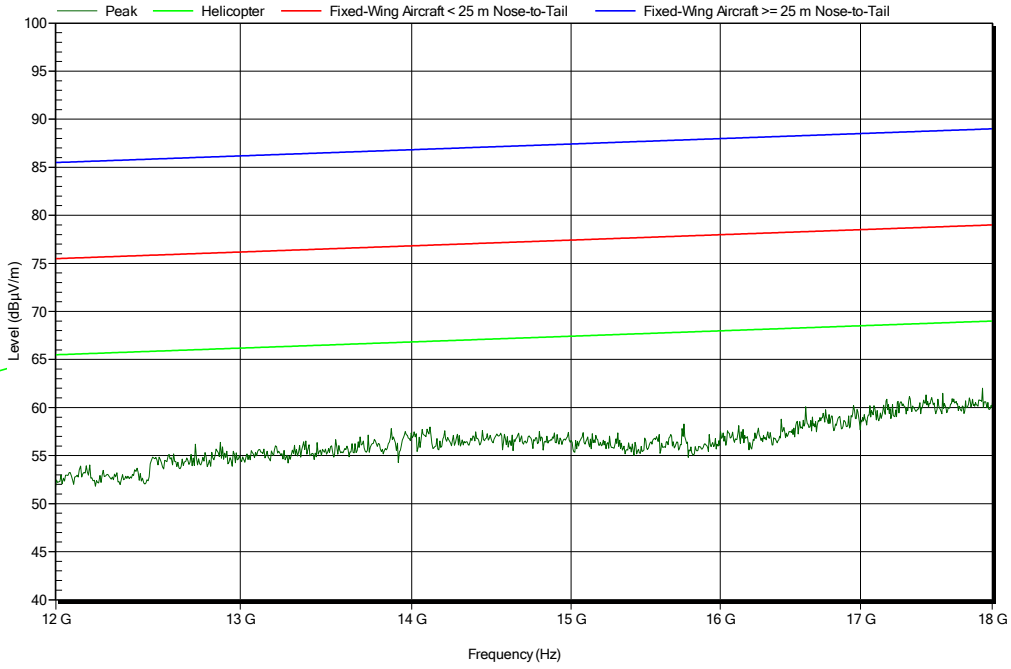
RE102: 8 - 12 GHz. Antenna polarity: Vertical. Lyric3 hearing aid. Time of Measurement: 4/6/2015 12:22:33 PM



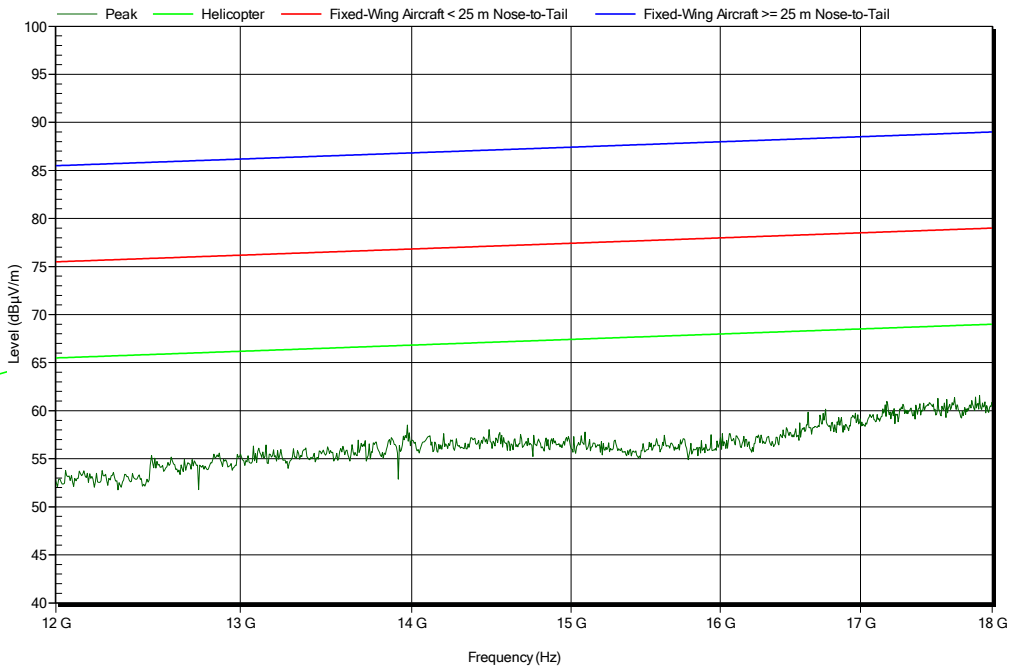
RE102: 8 - 12 GHz. Antenna polarity: Horizontal. Lyric3 hearing aid. Time of Measurement: 4/6/2015 11:59:19 AM



RE102: 12 - 18 GHz. Antenna polarity: Vertical. Lyric3 hearing aid. Time of Measurement: 4/6/2015 12:24:35 PM



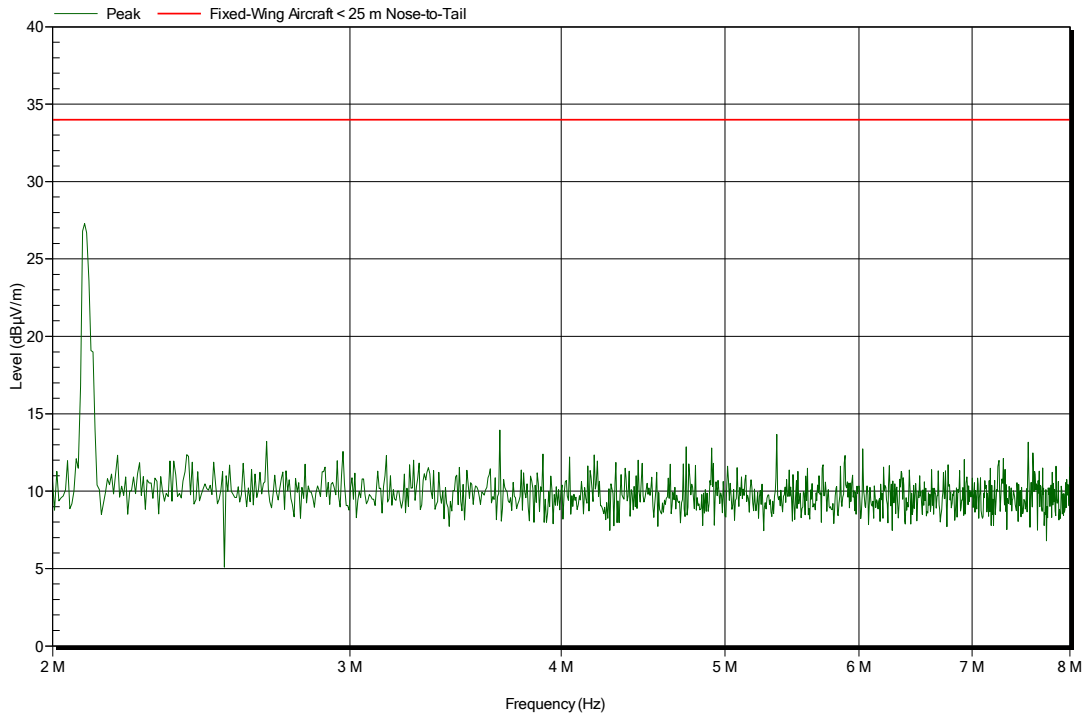
RE102: 12 - 18 GHz. Antenna polarity: Horizontal. Lyric3 hearing aid. Time of Measurement: 4/6/2015 12:01:23 PM



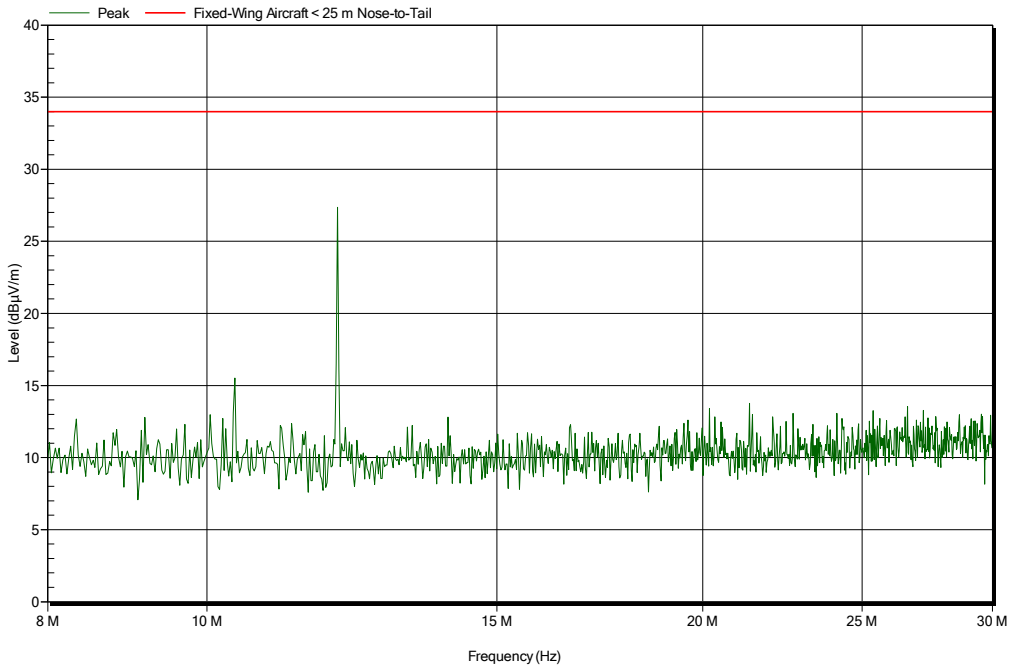
3.1.2.2 RE102 System Accuracy Scans

The following scans are performed to verify the integrity of the measurement setup prior to testing. A calibrated signal is applied at the antenna connection that is equivalent to a level that is 6 dB below the MIL-STD-461 limit. The indicated level on the plot should be 6 dB +/- 3 dB from the limit line.

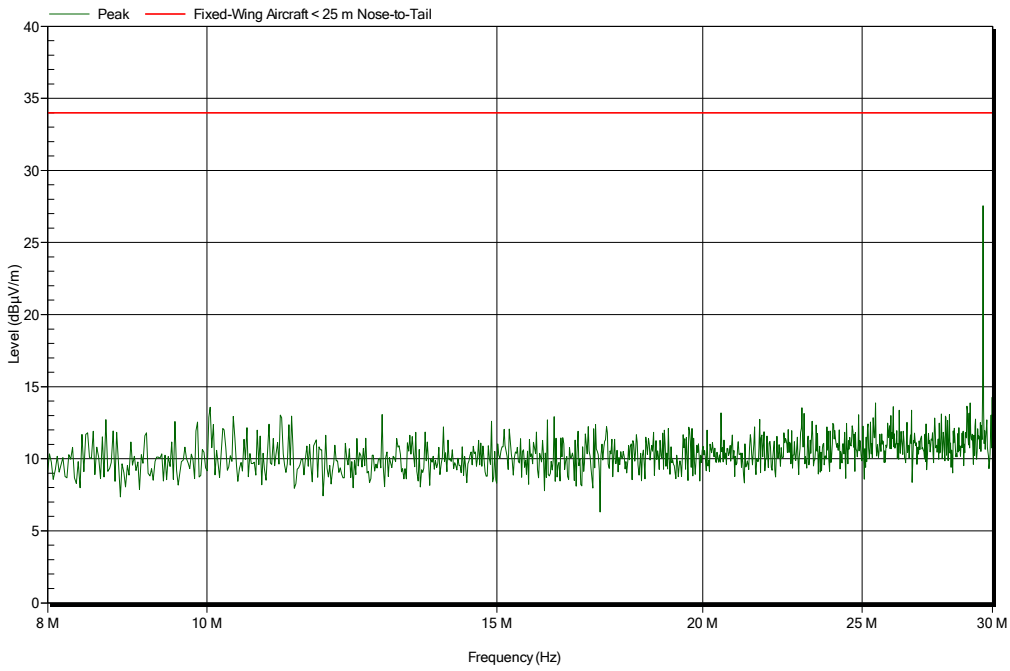
RE102: 2 - 8 MHz, 2.1 MHz. System accuracy. The indicated level on the plot should be 6 dB +/- 3 dB from the limit line. Time of Measurement: 4/6/2015 10:16:51 AM



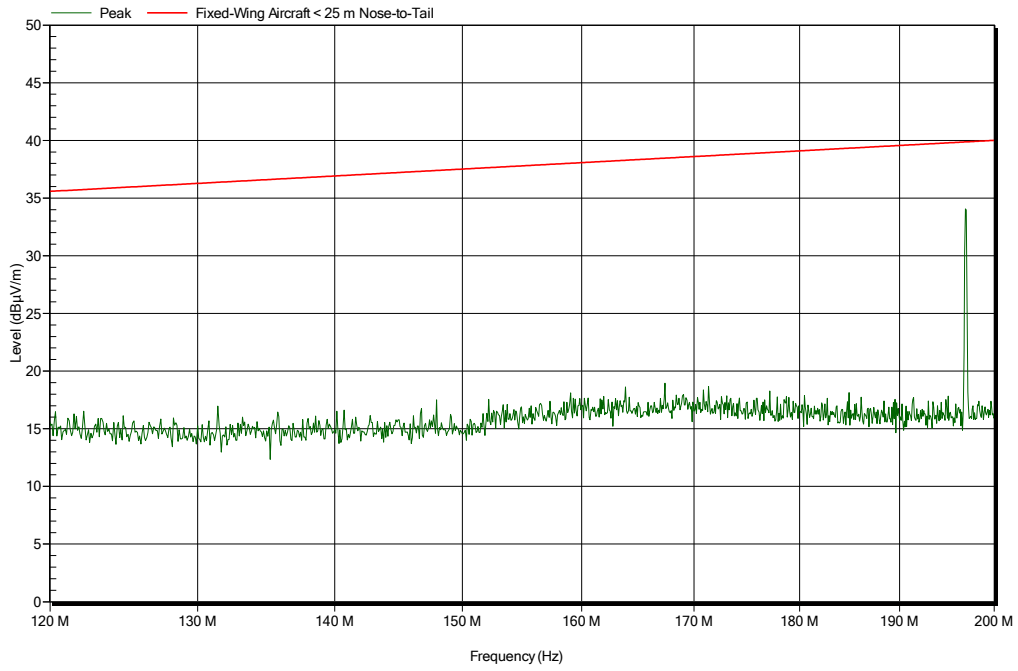
RE102: 8 - 30 MHz, 12 MHz. System accuracy. The indicated level on the plot should be 6 dB +/- 3 dB from the limit line. Time of Measurement: 4/6/2015 10:17:49 AM



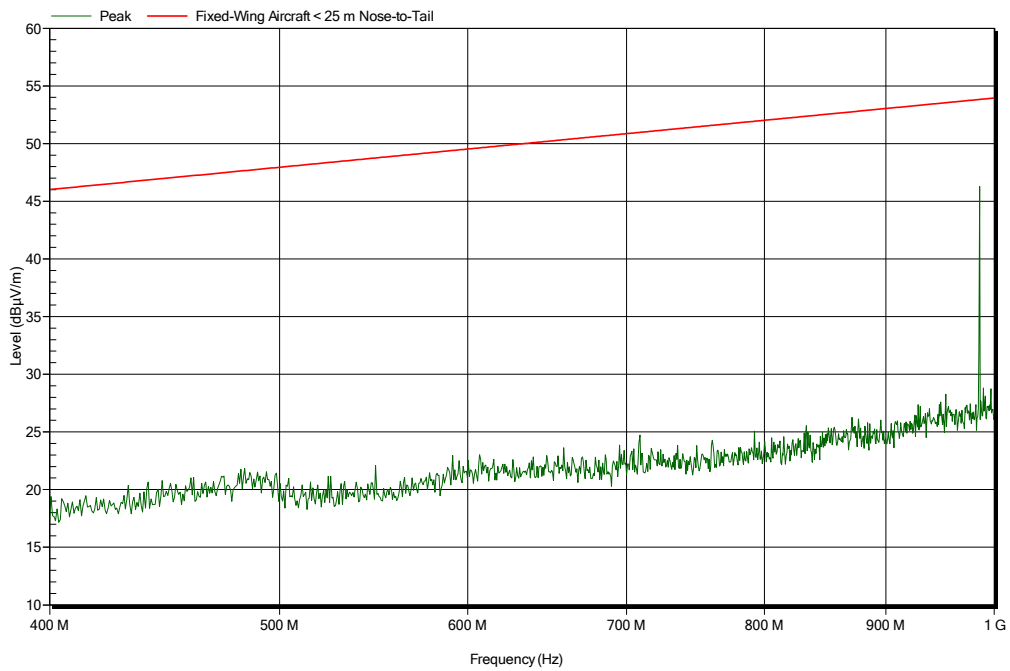
RE102: 8 - 30 MHz, 29.5 MHz. System accuracy. The indicated level on the plot should be 6 dB +/- 3 dB from the limit line. Time of Measurement: 4/6/2015 10:18:46 AM



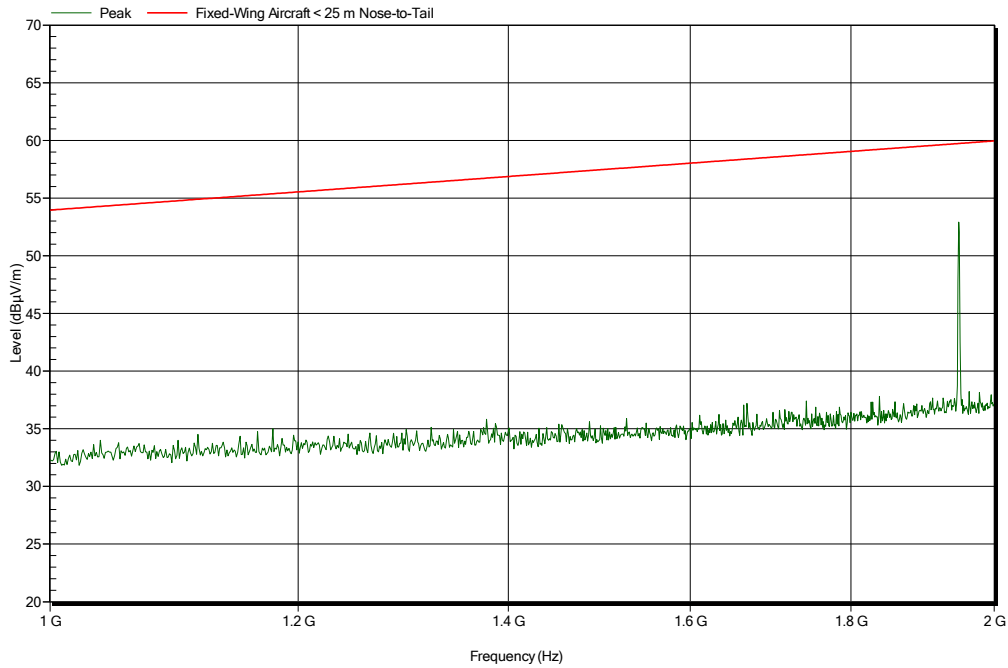
RE102: 120 - 200 MHz, 197 MHz. System accuracy. The indicated level on the plot should be 6 dB +/- 3 dB from the limit line. Time of Measurement: 4/6/2015 10:31:09 AM



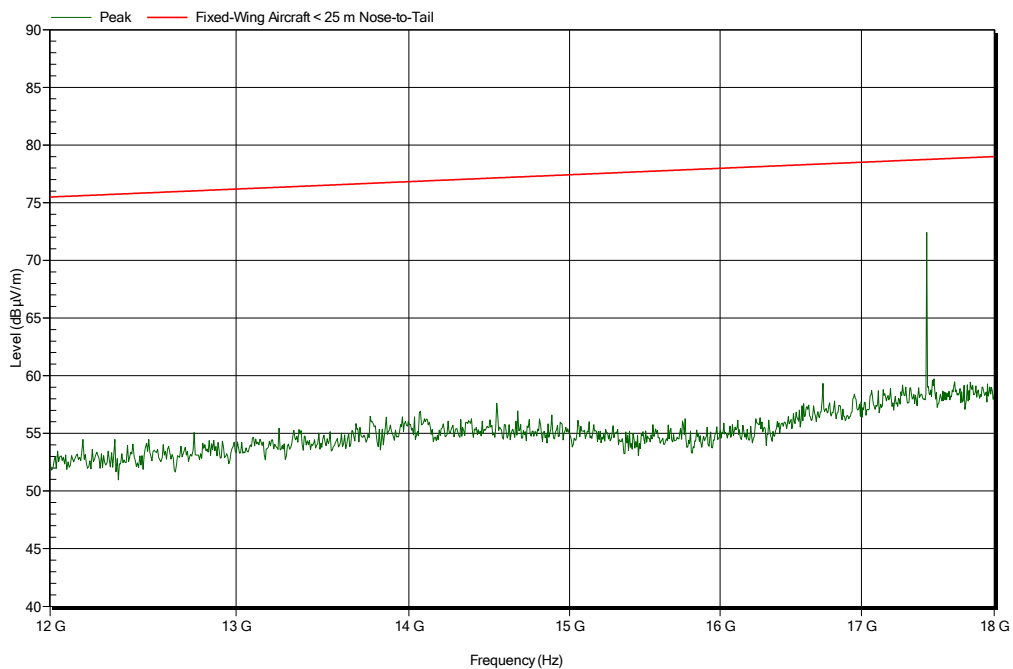
RE102: 400 - 1000 MHz, 990 MHz. System accuracy. The indicated level on the plot should be 6 dB +/- 3 dB from the limit line. Time of Measurement: 4/6/2015 10:53:30 AM



RE102: 1 - 2 GHz, 1.95 GHz. System accuracy. The indicated level on the plot should be 6 dB +/- 3 dB from the limit line. Time of Measurement: 4/6/2015 11:41:43 AM



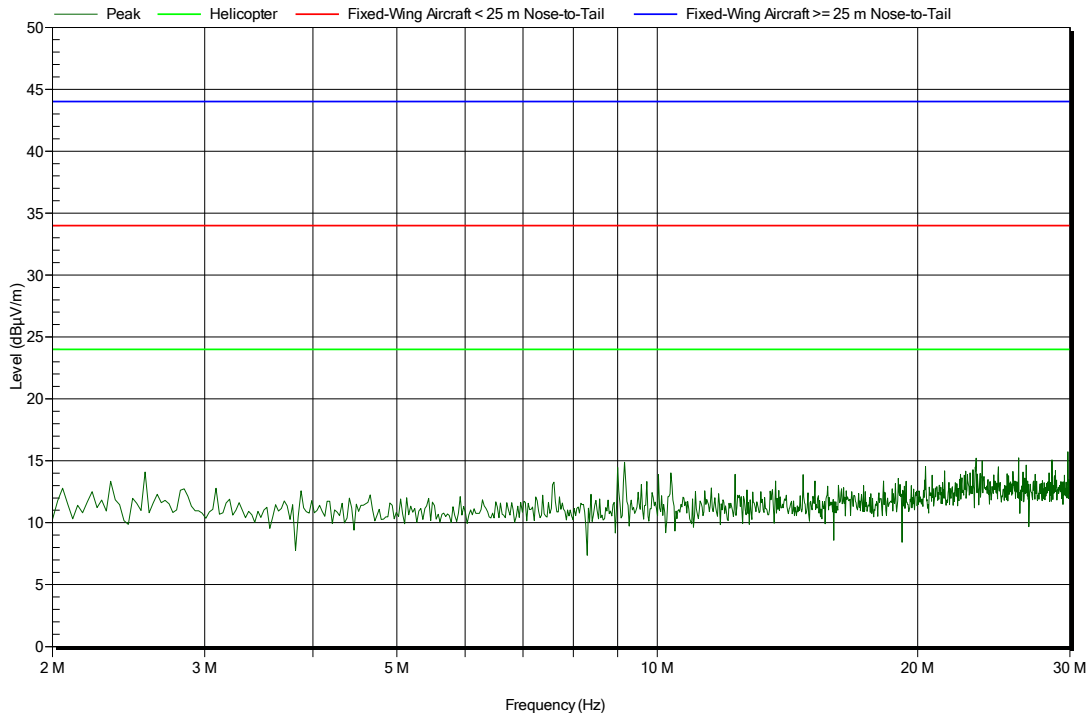
RE102: 12 - 18 GHz, 17.5 GHz. System accuracy. The indicated level on the plot should be 6 dB +/- 3 dB from the limit line. Time of Measurement: 4/6/2015 11:45:03 AM



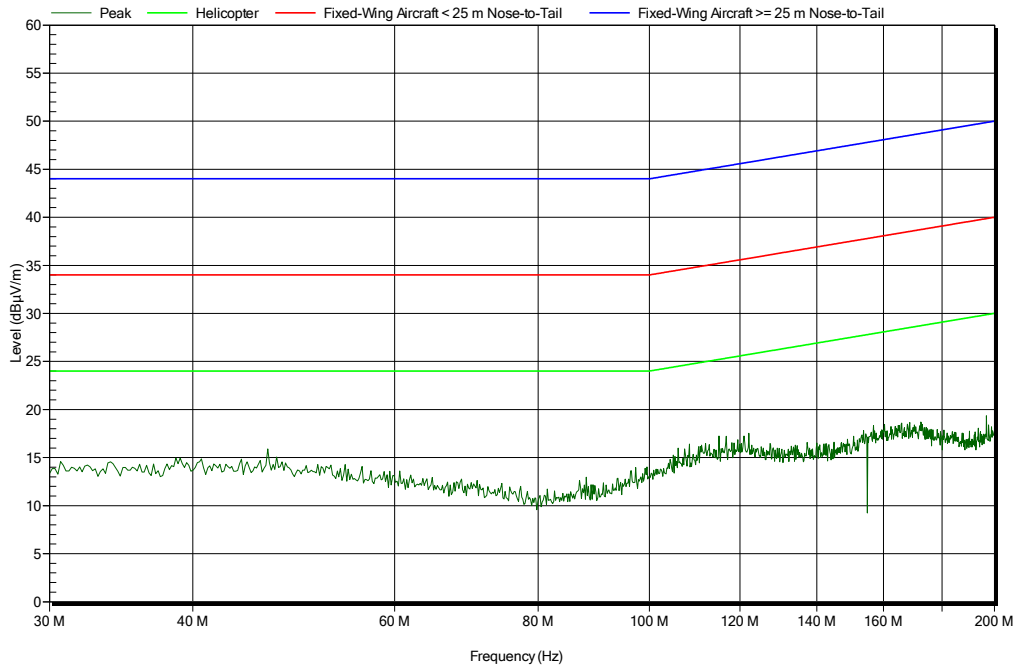
3.1.2.3 RE102 Ambient Scans

The following scans are performed to measure the conditions in the shielded room with the EUT turned off. Measured levels should be at least 6 dB below the MIL-STD-461 limit.

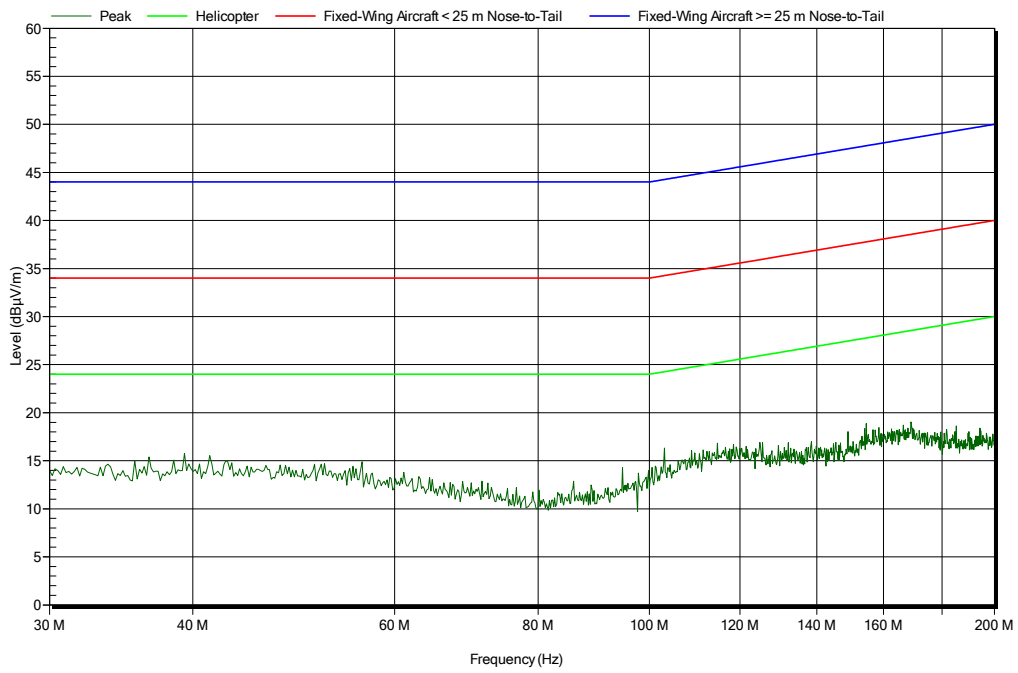
RE102: 2 - 30 MHz Ambient. Time of Measurement: 4/6/2015 10:22:03 AM



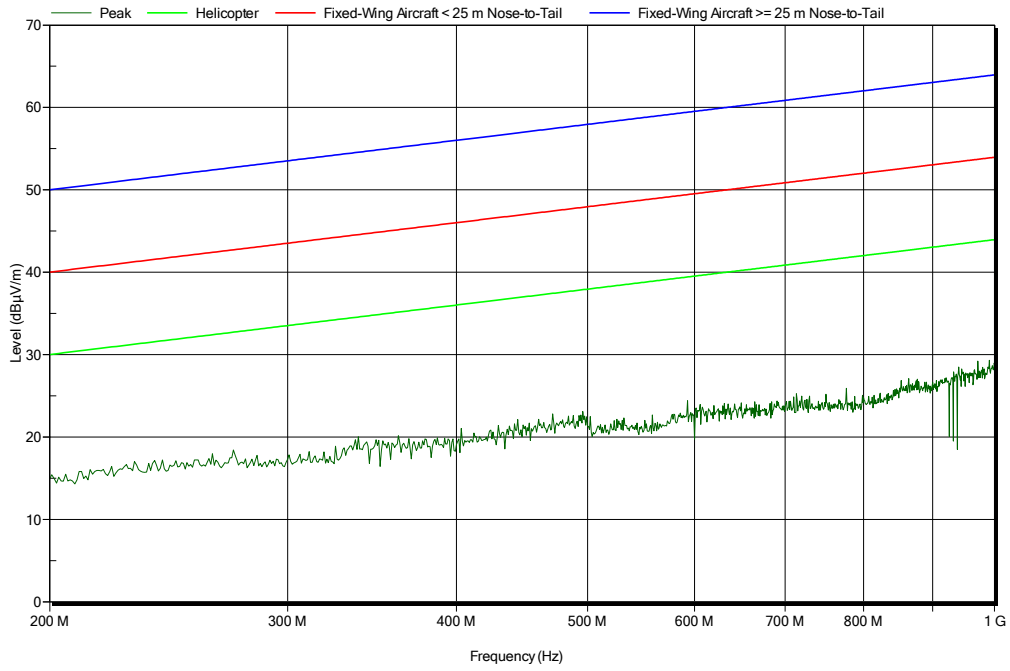
RE102: 30 - 200 MHz Ambient. Antenna polarity: Vertical. Time of Measurement: 4/6/2015
10:41:54 AM



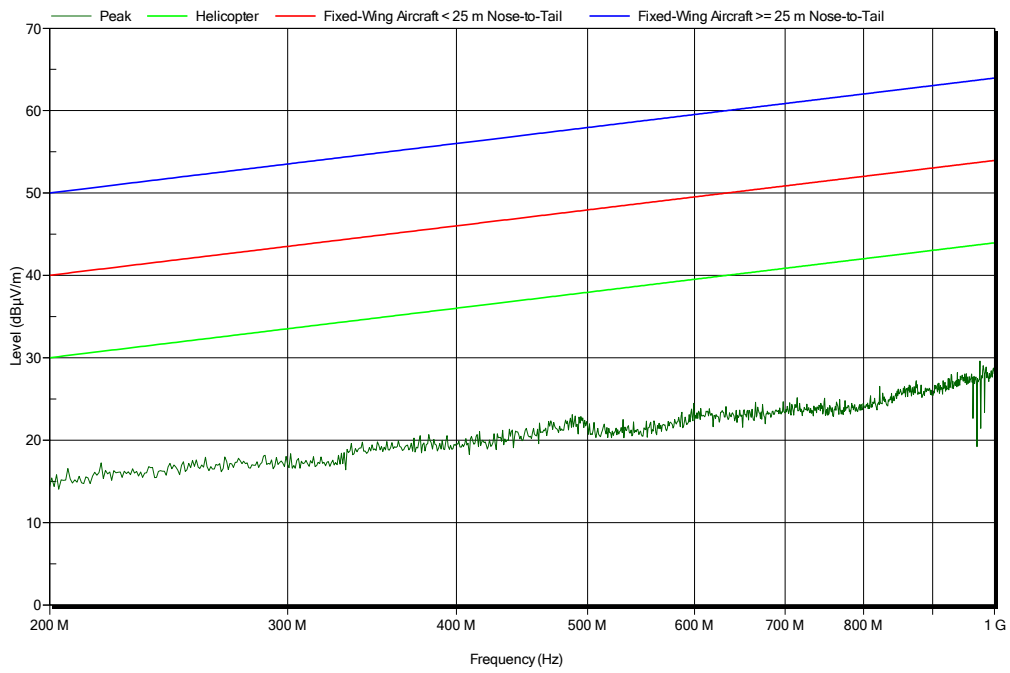
RE102: 30 - 200 MHz Ambient. Antenna polarity: Horizontal. Time of Measurement: 4/6/2015
10:34:21 AM



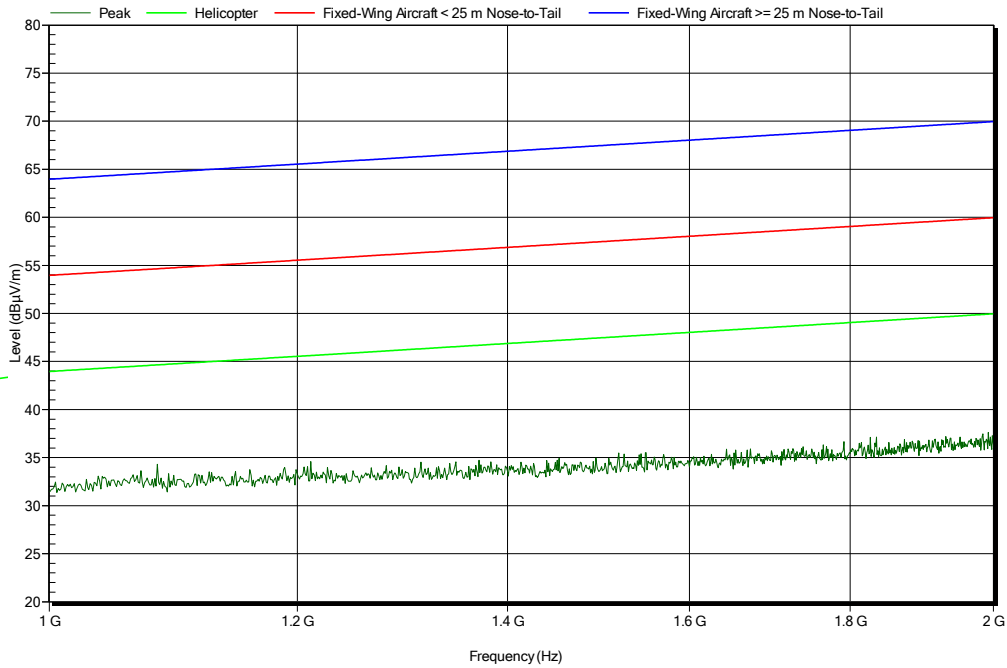
RE102: 200 - 1000 MHz Ambient. Antenna polarity: Vertical. Time of Measurement: 4/6/2015 11:05:05 AM



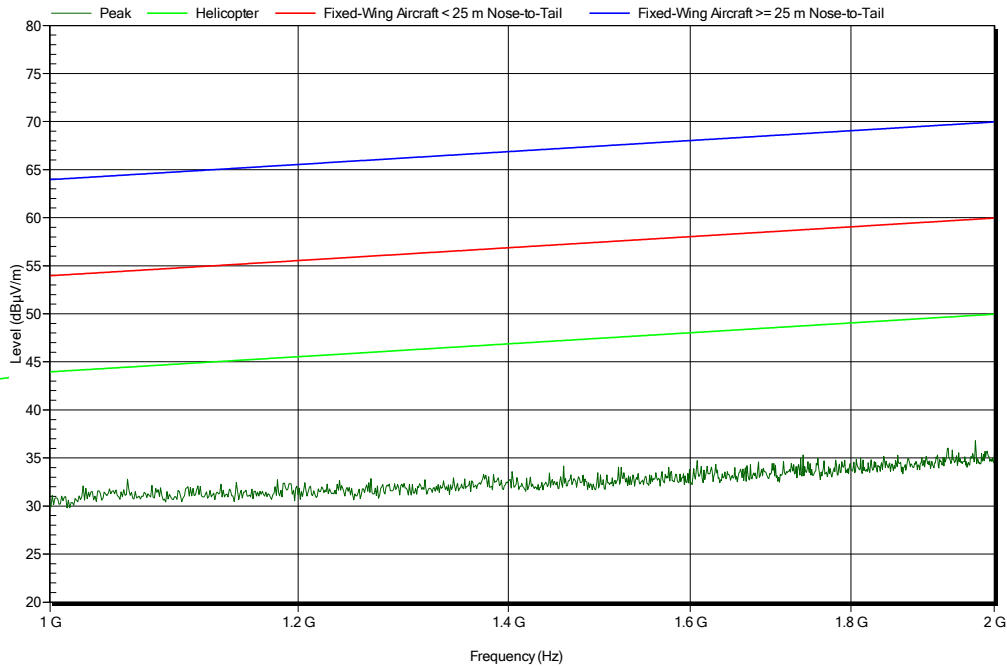
RE102: 200 - 1000 MHz Ambient. Antenna polarity: Horizontal. Time of Measurement: 4/6/2015 11:20:08 AM



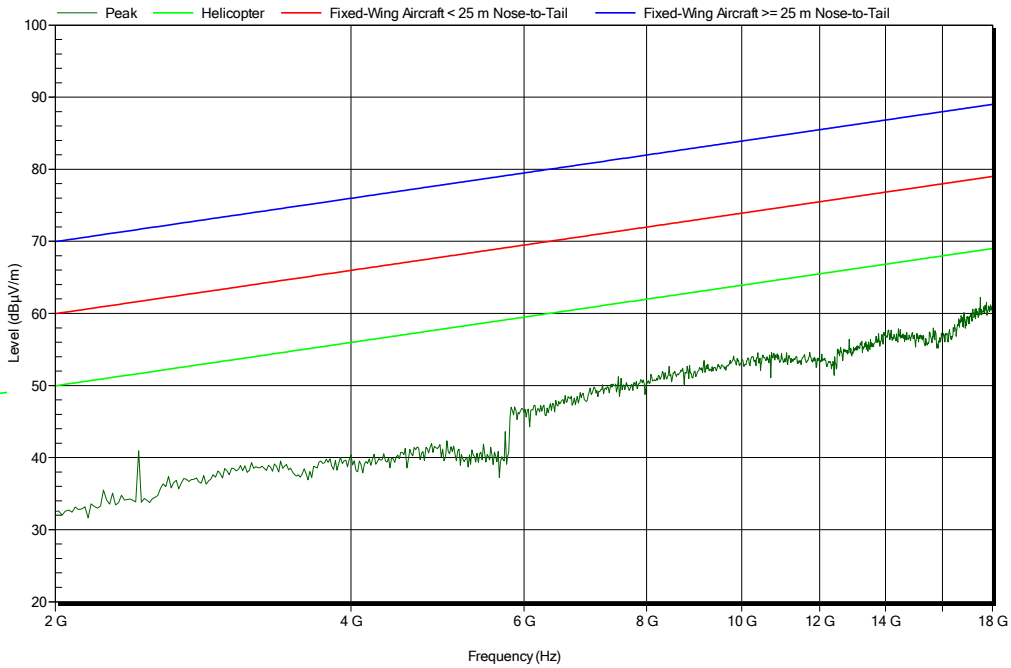
RE102: 1 - 2 GHz Ambient. Antenna polarity: Vertical. Time of Measurement: 4/6/2015
12:14:14 PM



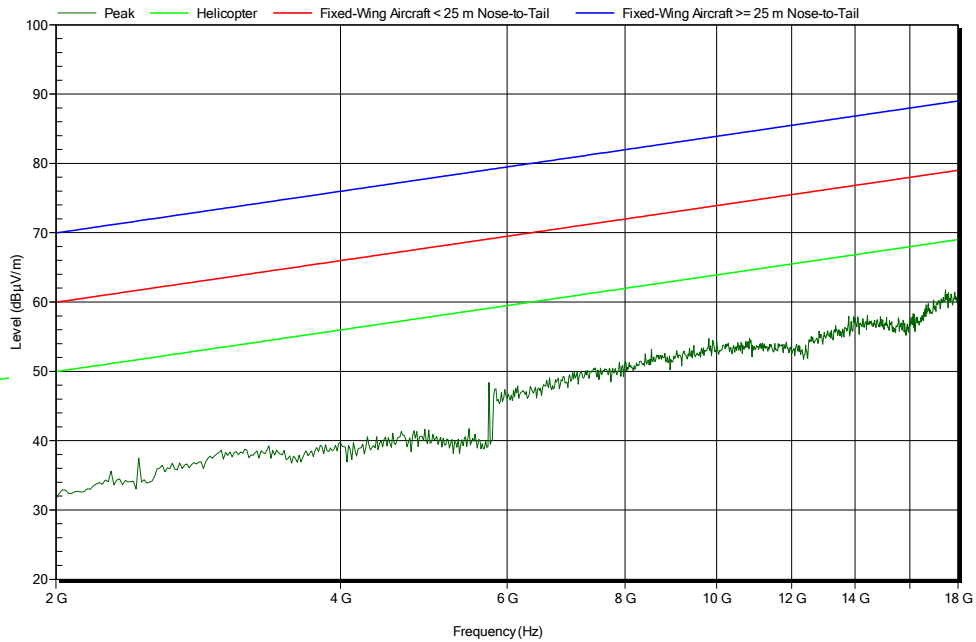
RE102: 1 - 2 GHz Ambient. Antenna polarity: Horizontal. Time of Measurement: 4/6/2015
11:53:05 AM



RE102: 2 - 18 GHz Ambient. Antenna polarity: Vertical. Time of Measurement: 4/6/2015
12:11:53 PM



RE102: 2 - 18 GHz Ambient. Antenna polarity: Horizontal. Time of Measurement: 4/6/2015
12:05:36 PM



3.2 RS103 Radiated Susceptibility, Electric Field, 2 MHz to 1 GHz

3.2.1 RS103 Measurement Conditions

The Lyric3 hearing aid and measurement conditions were set up in accordance with MIL-STD-461F requirements. Test equipment and photos of most of the setups were as shown below.

RS103 Test Equipment

Manufacturer	Model	Function	Serial #	Cal Due
Hewlett Packard	8566B	Spectrum Analyzer	1925A00293/ 1928A00992	5/26/15
Hewlett Packard	85685A	Preselector	3506A01584	NCR
Hewlett Packard	8112A	Pulse Generator	2633G04733	6/17/16
Hewlett Packard	8642B	Signal Generator	2618A02361	12/29/15
Hewlett Packard	8373E	Signal Generator	2821A00442	9/2/15
Amplifier Res	1000L	Power Amplifier	22329	NCR
Amplifier Res	1000HA	Power Amplifier	5131	NCR
Logimetrics	A610/LS	Power Amplifier	6206	NCR
Logimetrics	A600/S	Power Amplifier	6193	NCR
Logimetrics	A600/C	Power Amplifier	6211	NCR
Logimetrics	A600/IJ	Power Amplifier	6222	NCR
Logimetrics	A610/P	Power Amplifier	6243	NCR
Amplifier Res	200T1G2	Power Amplifier	19621	NCR
Amplifier Res	AT1080	Log Periodic Antenna	20230	NCR
Amplifier Res	AT5000	Transmission Line	22468	NCR
AEL	H-4901	Horn Antenna	169	NCR
AEL	H-5000R	Horn Antenna	200	NCR
AEL	H-5101	Horn Antenna	351	NCR
AEL	H-5201	Horn Antenna	336	NCR
AEL	H-5302	Horn Antenna	147	NCR
AEL	H-1458	Horn Antenna	211	NCR
Amplifier Res	FP5240	Field Probe	26984	7/09/15
Amplifier Res	FP5240	Field Probe	26983	10/14/16
Amplifier Res	FM5400	Field Monitor	27329	NCR

Calibration requirements and designations per the US Air Force Calibration Authority
NCR - No Calibration Required

Evaluations were performed at 100 Volts/meter from 2 MHz to 1 GHz and 200 Volts/meter from 1 to 18 GHz. Testing was performed for both vertical and horizontal polarization from 30 MHz and 18 GHz. Per MIL-STD-461F, only vertical polarization was used from 2 to 30 MHz.

The frequency bands were automatically scanned under computer control. The field was automatically leveled by the computer receiving the field level from the FM 5004 Field Monitor and adjusting the output of the signal generators as necessary. The required field level was adjusted based on the modulation. For example, 14.3 Volts/meter displayed on the FM5400 is

equivalent to a 20 Volt/meter peak RMS field. Frequency step sizes were as listed in the following table.

Frequency Step Size

Frequency (MHz)	Step Size
2.0 – 30.0	$0.01 * f_0$
30.0 - 1000	$0.005 * f_0$
1000 - 18000	$0.0025 * f_0$

Photos of the test setups are shown below.



2 - 120 MHz, Vertical Polarization



30 - 120 MHz, Horizontal Polarization



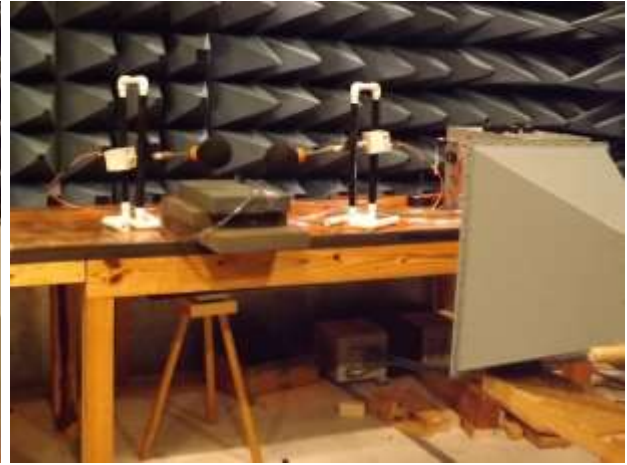
120 - 500 MHz, Vertical Polarization



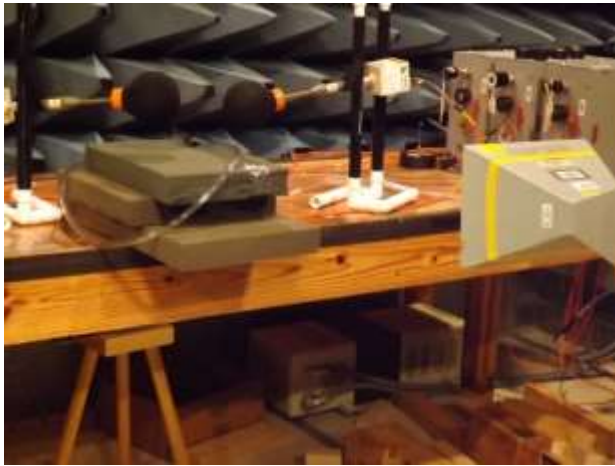
120 - 500 MHz Horizontal Polarization



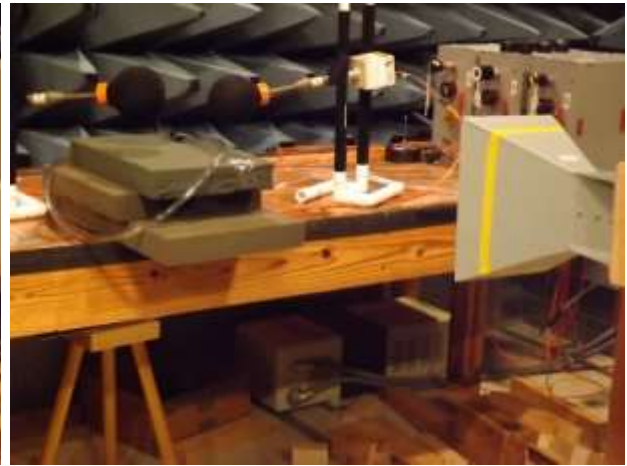
500 - 1000 MHz, Vertical Polarization



500 - 1000 MHz Horizontal Polarization



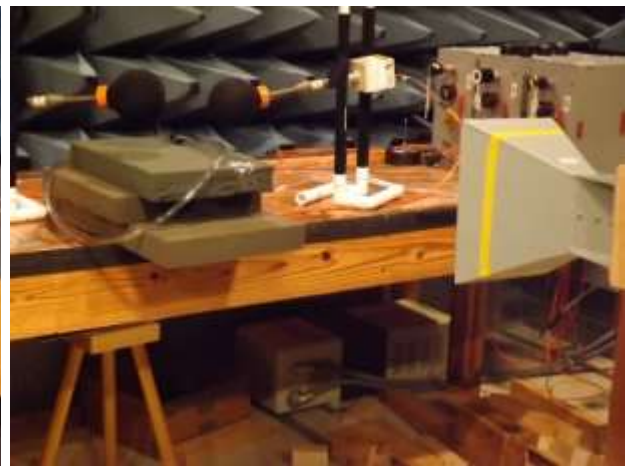
1000 - 2000 MHz, Vertical Polarization



1000 - 2000 MHz Horizontal Polarization



2000 - 4000 MHz, Vertical Polarization



2000 - 4000 MHz Horizontal Polarization



4000 - 8000 MHz, Vertical Polarization



4000 - 8000 MHz Horizontal Polarization



8000 - 12400 MHz, Vertical Polarization



8000 - 12400 MHz Horizontal Polarization



12400 - 18000 MHz, Vertical Polarization



12400 - 18000 MHz Horizontal Polarization

3.2.2 RS103 Results

The Lyric3 hearing aid passed exhibiting no responses. See tables below. Minor distortion (10%) was observed during the 1 to 2 GHz scans, but the “noise” was not detectable to us (using our ears). The basic pass/fail criteria for this testing was to identify any squelching cause by RF fields that may lead to discomfort or the risk of hearing loss.

Vertical Polarization

Frequency Range (MHz)	Test Level (Volts/meter)	Result
2 - 100	100	Passed
100 - 220	100	Passed
220 - 400	100	Passed
400 - 1000	100	Passed
1000 - 2000	200	Passed
2000 - 4000	200	Passed
4000 - 8000	200	Passed
8000 - 12400	200	Passed
12400 - 18000	200	Passed

Horizontal Polarization

Frequency Range (MHz)	Test Level (Volts/meter)	Result
30 - 100	100	Passed
100 - 220	100	Passed
220 - 400	100	Passed
400 - 1000	100	Passed
1000 - 2000	200	Passed
2000 - 4000	200	Passed
4000 - 8000	200	Passed
8000 - 12400	200	Passed
12400 - 18000	200	Passed

The following testing was included since there were rumors of store security systems affecting the unit:

Scanned from 120 kHz to 140 kHz and 13 MHz to 14 MHz, 100 V/m, using a 1500 Hz sine, square and sawtooth waveforms.

Testing in the 500 MHz to 4 GHz frequency range, several scans were taken with the hearing aid rotated 90° in the horizontal plain.