WICHITA STATE UNIVERSITY
NATIONAL INSTITUTE FOR AVIATION RESEARCH

Background Information for Transmissions Used During Aircraft EMC Test Methods

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WICHITA STATE UNIVERSITY | National Institute for Aviation Research | 1845 Fairmount Street | Wichita, Kansas 67260-0093
tele: (316) 978-6427 | fax: (316) 978-3175 | web: www.niar.wichita.edu

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Executive Summary

This document provides supporting information for NIAR customers requiring platform level High Intensity Radiated Field (HIRF) testing on external sites (e.g., airfields or other open area sites). Customers should use this supporting information as part of their application for obtaining a radio transmission licenses for -aircraft ground testing.

This document provides a brief description of the radiated test methods employed to assess the coupling on aircraft platforms employing two low level test methods. The information contained within this document includes: antenna types, transmit powers, test distances, typical E-field strength figures, antenna gains (dBi), Effective Radiated Powers, frequency step size and dwell times.

The tests described within this document are performed at both low power levels and use swept frequency techniques, and as such the dwell times employed are in the order of milliseconds (MS) for each discrete frequency within the sweep.

As part of the process to certify, aircraft platforms tests are performed to assess the aircrafts immunity to interference caused by external Radio Frequency (RF) signals. The test methods used to assess the coupling to the aircraft over the frequency range 1 MHz to 18 GHz are described briefly within this document. This background information provides both customers and licensing authorities with the required test parameters to support the transmission license application process.

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1 Introduction

1.1 Background Information

1.1.1 In order to certify a new aircraft model or variant it must be tested against a number of standards. These include those applicable to structural integrity, aerodynamic airworthiness, operating limitations, passenger safety and, of particular interest for this document, Electromagnetic Compatibility (EMC).

1.1.2 The test methods employed and described within this document have been used for various aircraft assessments over the past 20 – 30 Years, the methods employed are in line with test standards such as Defence Standard 59-411, Part 4, dated January 2008 and the Guide to Certification of Aircraft In a High Intensity Radiated Field (HIRF) Environment – EUROCAE ED-107A / SAE ARP5583A, dated July 2010.

1.1.3 In addition to ensuring that no aircraft system interferes with any other, this latter standard also considers the effect of external radiated fields on the aircraft's systems.

1.1.4 Evaluating the immunity of an aircraft system to effects from E-fields consists of at least the first three of the following four stages.

1. As part of the design of the aircraft, engineering judgments are made to determine the expected coupling of the external fields onto the components of each system.
2. This expected coupling is then used to set bench-test levels to which the system manufacturer is required to test their individual system for susceptibility.
3. Once the aircraft has been built measurements are made to determine the actual coupling of the fields to the aircraft systems.
4. If these measurements show that the levels measured are below those predicted, i.e., the design assumptions were correct, then the bench-testing is considered to be sufficient to certify the aircraft. If not, any shortfall (which may not cover the whole frequency bands) can be supplemented either by further bench testing or by on-aircraft susceptibility testing.

1.1.5 The aircraft avionics systems may suffer interference through system wiring (cable bundles) acting as antennas. This induces RF currents to flow in the wiring over and above what is intentionally generated by the system during operation. These "false" signals may then be interpreted by the system as a command to which it responds, thereby upsetting its normal operation. RF interference can also cause systems to 'lock up' or even suffer damage if systems are exposed to high levels of RF in operation.

1.1.6 At the lower end of the frequency range (below 400 MHz) this coupling is usually induced on the aircraft wiring connecting either individual equipment of the same system or two separate systems. This is referred to as "cable coupling".

1.1.7 Above approximately 400 MHz the coupling mechanism also becomes one of "aperture coupling" whereby the shorter wavelength field penetrates the actual boxes of the system and then induces false signals on the shorter internal wiring (i.e., Printed Circuit Board (PCB)) tracks within the system.

1.1.8 The measurements, test equipment, and techniques performed in stages 3 and 4 are therefore very different above and below 400 MHz to reflect the change in coupling mechanism.

1.2 Test Philosophy

1.2.1 The initial coupling measurements are conducted at a level designed to minimize the impact to third parties (other users of the Frequency Spectrum) through the use of very low power levels. Below 400 MHz the technique used is Low Level Swept Current (LLSC) and above 400 MHz it is Low Level Swept Field (LLSF). For both techniques the E-fields produced are measured to be approximately 1 to 2 V/m, measured at the aircraft position. The transmissions are also of a swept nature, and as such any interference at discrete frequencies is very limited.

1.2.2 The LLSC and LLSF coupling test techniques are described in more detail within the following sections of this document.

2 Low Level Swept Current (LLSC)

2.1 This technique is used from 0.5 to 400 MHz to measure the RF current induced on an aircraft cable bundle and, using figures determined during a pre-calibration, normalize this current to that which would be induced by an incident field of 1 V/m.

2.2 The aircraft is illuminated from all four sides in turn using transmit antennas horizontally and vertically polarized in turn. The frequency range is divided into a number of bands to allow for the properties and efficiencies of the transmitting antennas employed. All LLSC transmissions are of an un-modulated Continuous Wave (CW) (Emission Designator - N0N) nature.

2.3 Each aircraft wire bundle to be measured is instrumented with a current probe whose output is fed back to the measurement receiver via a Fiber Optic Link (FOL). Typical current probes and a FOL system are illustrated, both in isolation and installed within a typical aircraft bay, in Figure 1.

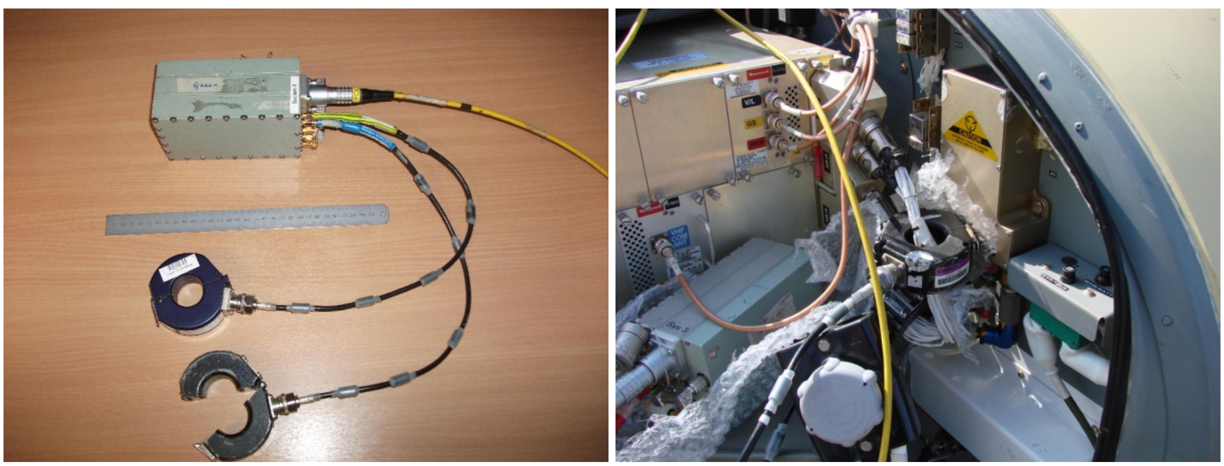

Figure 1 – LLSC Current Probes and FOL

2.4 Typical current probes can be used over the whole frequency range from 0.5 to 400 MHz and therefore do not need changing at any point during the measurements. The transmit antennas are, however, more restricted over their range of operation and therefore various antennas are used for different frequency bands.

2.5 From 0.5 to 45 MHz HF dipole antennas are used and from 40 to 400 MHz Bi-Log type antennas are employed. These are illustrated in Figure 2. The specific transmit antennas and associated parameters are as detailed within Table 1.

2.6

Transmit Antenna	**Make/Model No.**	**Frequency Range**	**Typical Gain**
HF Dipole(s)	NIAR manufactured – HF dipoles (or equivalent)	1 MHz – 45 MHz	At tuned length, 2.15 dBi
Bi-Log	Chase CBL 6111 or CBL6121A (or equivalent)	40 MHz – 400 MHz	40 MHz, -12 dBi 100 MHz, 0 dBi 400 MHz, 6 dBi

Table 1 – LLSC transmit antenna information

2.7 These antennas are fed from a spectrum analyzer via a 100 W broadband amplifier and 50 m long cables. For the Low HF band (0.5 to 25.5 MHz) and HF band (25 to 45 MHz) the drive level used is usually 0 dBm from the RF tracking source and for the VHF (40 to 205 MHz) and UHF (200 to 400 MHz) bands it is typically -10 dBm. This implies that the forward power to the HF antennas is typically (accounting for transmit cable loss) 70-80 Watts. For the VHF and UHF frequencies the forward power to the antennas is less than 10 Watts.

Figure 2 – LLSC Antennas – HF Dipole Horizontal & Vertical and Bi-Log Vertical

2.8 For each of the four bands the analyzer and source are set to track across the frequency band with a sweep-time of typically 500 mS which, given that there are 401 frequencies over each sweep, relates to an approximate dwell time at each discrete frequency of 1 mS.

2.9 The test set-up for LLSC measurements in the V/UHF bands is shown schematically in Figure 3.

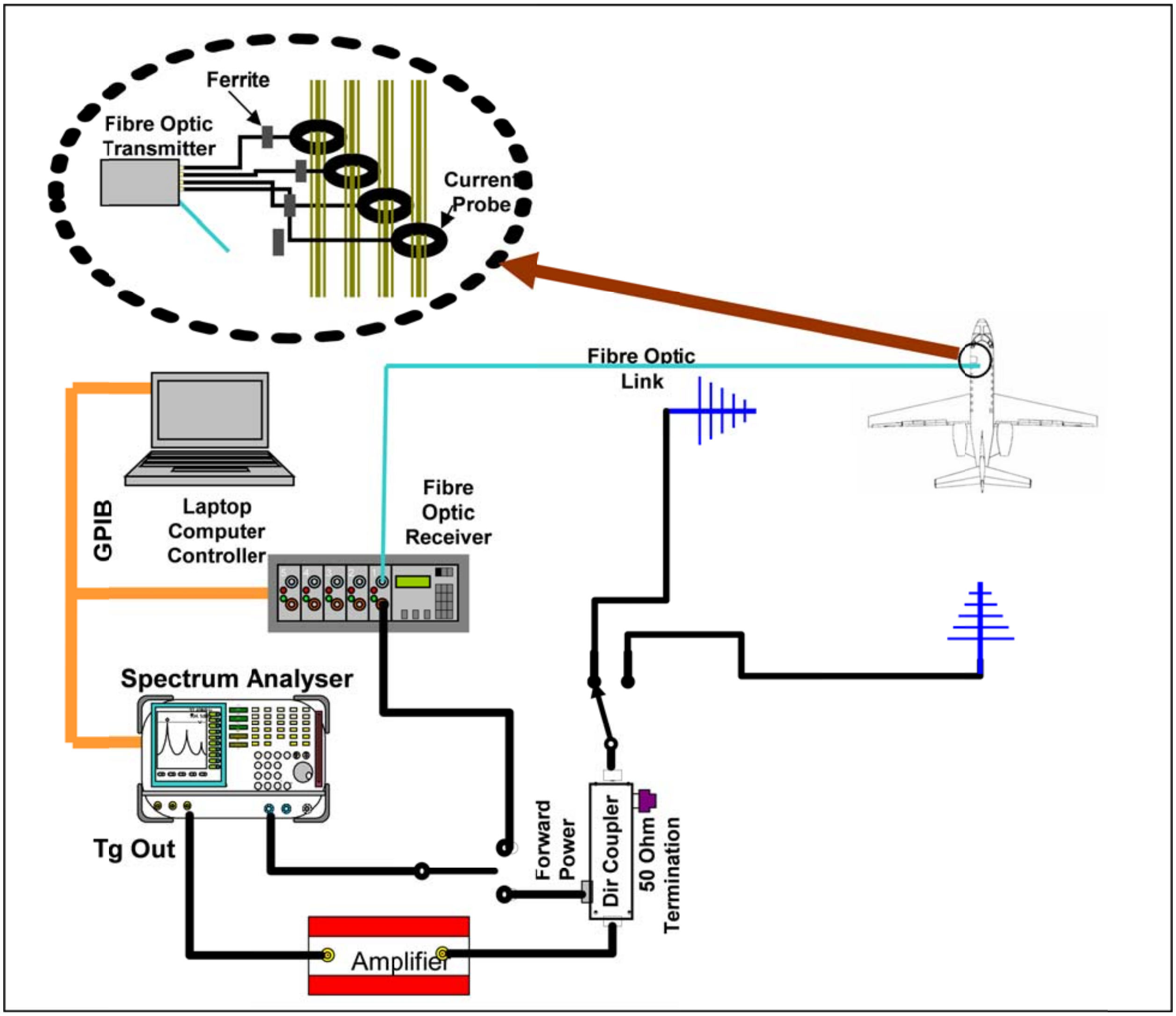

Figure 3 – LLSC Test Set-up Schematic

2.10 Typical figures associated with LLSC measurements are shown in Table 2. The last two columns show the approximate field at the aircraft location (25 m from transmit antenna) and at a further range of 100 m from the transmit antenna.

Freq	Sweep Time	TG level	Amp Gain	Cable Loss	Ant Base Power		Ant Gain	EiRP	ERP		Freq Steps	Field @ 25m	Field @ 100m
MHz	ms	dBm	dB	dB	dBm	W	dBi	dBm	dBm	W		V/m	V/m
1	500	0	50	0.76	49.24	83.95	2.15	51.39	49.24	83.95	501	2.01	0.50
25.5				1.24	48.76	75.16		50.91	48.76	75.16		1.90	0.47
25	500	0	50	1.22	48.78	75.51	2.15	50.93	48.78	75.51	501	1.90	0.48
45				1.70	48.30	67.61		50.45	48.30	67.61		1.80	0.45
40	500	-10	50	1.60	38.40	6.92	-12.00	26.40	24.25	0.27	501	0.11	0.03
205				3.94	36.06	4.04	6.00	24.06	21.91	0.16		0.09	0.02
200	500	-10	50	3.87	36.13	4.10	6.00	42.13	39.98	9.95	501	0.69	0.17
400				5.79	34.21	2.64		40.21	38.06	6.40		0.55	0.14

Table 2 – Typical LLSC Transmission Parameters

2.11 It should be noted that the HF dipoles are used over a broad frequency range and their length is adjusted (by the physical addition/removal of elements) for different frequency bands. The idealized Antenna Gain figure quoted in the table above (2.15 dBi) only holds true at the tuned frequency corresponding to the length of the antenna. As the HF antennas are used over such a wide frequency range either side of the antennas tuned frequency the antennas efficiency and thus the antenna gain is significantly lower than the figures stated above, hence the field generated will also be significantly lower than that quoted, either side of the antennas tuned frequency.

2.12 For the calibration stage, which occurs prior to placing the aircraft on the test site, all transmission parameters are as above. A receive sensor is placed in the center of the test site and the field generated by each transmit antenna is measured in turn.

2.13 The current induced on the aircraft cable bundles are considered to be caused by the field level measured during the calibration. If this current is then divided by the calibration field level it is normalized to give the current that would be induced by a 1 V/m incident field. Since both the current and field measurements are taken in terms of dB this division actually takes the form of a subtraction.

2.14 Once data has been collected for each cable bundle for all four illumination angles and both polarizations all the data for each wire bundle is combined and a ‘worst case’ figure (i.e. highest coupling) is determined for each frequency.

2.15 The resulting figure can then be multiplied by the target environment at each frequency to determine the current that would be induced when the aircraft was exposed to the ‘real’ RF threat environment.

2.16 This final figure is that which will be compared to the induced current applied during the bench-level conducted susceptibility testing of the relevant system.

3 Low Level Swept Field (LLSF)

3.1 This technique is employed from typically 100 MHz to 18 GHz to measure the shielding/attenuation offered by the aircraft. Using this figure of attenuation the field strength seen by an aircraft system located at the test position should the aircraft be exposed to the full-threat can then be calculated.

3.2 Each required test location on the aircraft is illuminated from up to eight aspect angles in turn using horizontally and vertically polarized antennas. The frequency range is divided into a number of frequency bands to allow for the physical properties and efficiencies of the transmitting and receiving antennas used. All LLSF transmissions are of an un-modulated CW (N0N) nature. Typically the transmit antennas are set-up at a height of between 1-4 meters, however, this is dependent upon the area of the aircraft being illuminated.

3.3 Each location in the aircraft to be measured is instrumented with a small receive antenna whose output is fed back either by a FOL (below 1 GHz) or a low-loss microwave cable (above 1 GHz) to the measuring receiver.

3.4 Above 1 GHz a low-loss microwave cable is used but this presents a challenge in that the typical losses of such a cable are approximately 1 dB per meter of cable at 18 GHz. This cable therefore has to be limited to a practical length of about 20 m to avoid limiting the dynamic range of the measurement.

3.5 Two different receive antennas are used in turn within the aircraft bay/zone since neither can satisfactorily cover the whole frequency range from 100 MHz to 18 GHz.

3.6 The two receive antennas used are illustrated, both in isolation and installed in aircraft, in Figure 4 and Figure 5.

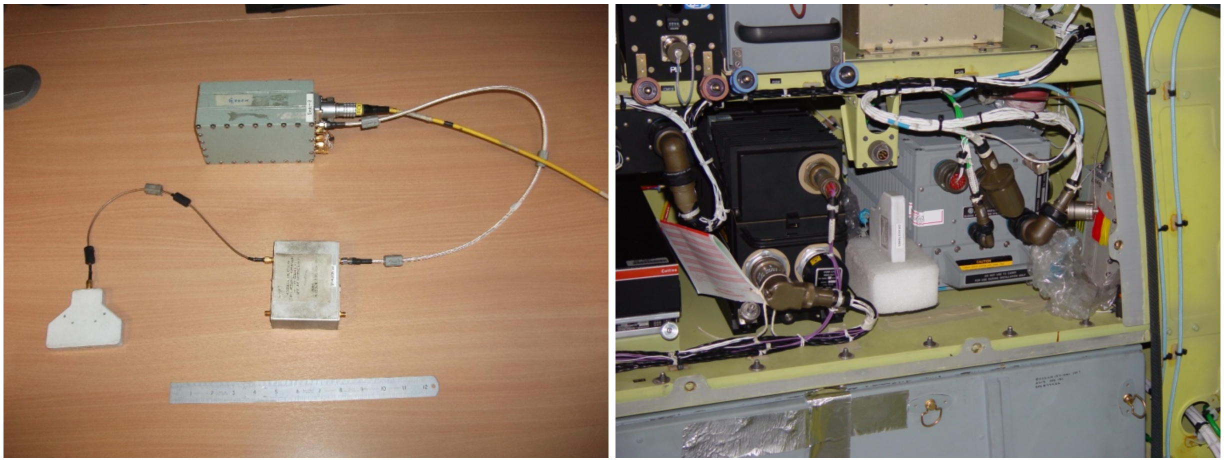

Figure 4 – LLSF Receive Antenna (Below 1 GHz) and FOL

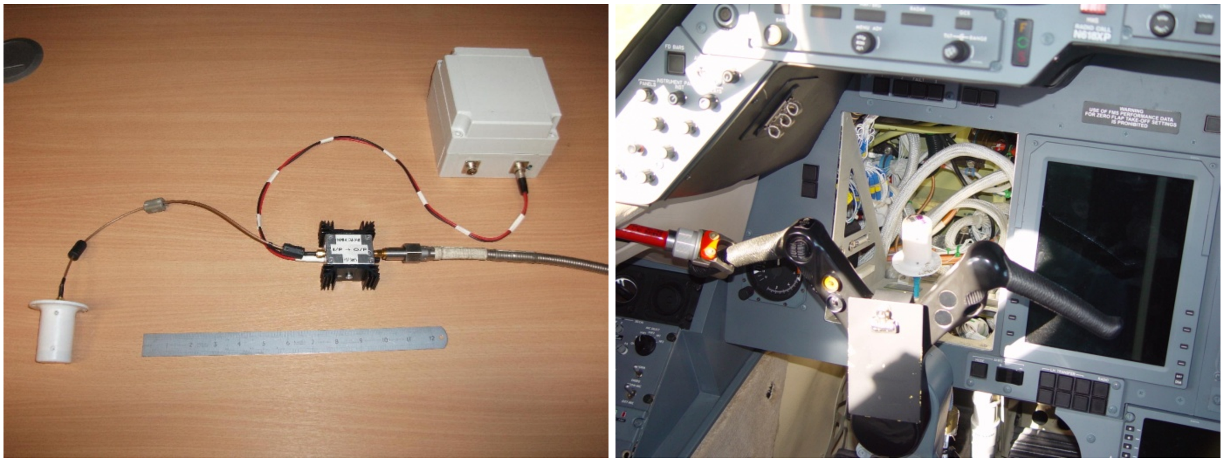

Figure 5 – LLSF Receive Antenna (Above 1 GHz) & Battery-powered Pre-amplifier

3.7 Two different transmit antennas are employed above and below 1 GHz. Up to 1 GHz a Bi-Log type antenna is used and above 1 GHz a wide band double-ridged guide horn (1-18 GHz) is employed. These are as illustrated in Figure 6.

Figure 6 – LLSF antennas – Bi-Log and Double-Ridged Guide Horn

3.8 The specific transmit antenna parameters for the LLSF test methods are as detailed in Table 3, showing the manufacturer, model numbers and typical gain figures over the frequency of use.

Transmit Antenna	Make/Model No.	Frequency Range	Typical Gain
Bi-Log	Chase CBL 6111 or CBL 6121A (or equivalent)	100 MHz to 1 GHz	100 MHz, 0 dBi 400 MHz, 6 dBi 800 MHz, 6 dBi 1 GHz, 6 dBi
Double Ridged Guide Horn	EMCO 3115 (or equivalent)	1 GHz to 18 GHz	1 - 4 GHz, 6.5 dBi 8 GHz, 8 dBi 12 GHz, 9.5 dBi 16 GHz, 12.5 dBi 18 GHz, 10.5 dBi

Table 3 – LLSF transmit antenna information

3.9 The antennas are driven from a tracking or signal generator, however, due to significant signal loss at the higher frequencies; transmit cables of up to 20 m in length are typically used. Below 1 GHz the gain available in the FOL (up to 33 dB) and the relatively low loss in the transmit cable allow transmissions to be made without the use of an amplifier in the transmit line.

3.10 Above 1 GHz some form of compensation for the losses in the transmit cable is required. A low-power amplifier is used; typically with a Gain of + 27 dB, which is installed close to the base of the transmit antenna. Note: A small battery-powered pre-amplifier is also used between the receive antenna and the microwave cable, to improve further the measurement dynamic range.

3.11 For each of the three frequency bands the analyzer and source are set to track across the frequency band with an associated sweep-time of typically 140 mS which, given that there are 401 frequencies in a sweep, gives an approximate dwell time at each discrete frequency of 0.3 mS.

3.12 The test set-up for LLSF measurements above 1 GHz is shown schematically in Figure 7.

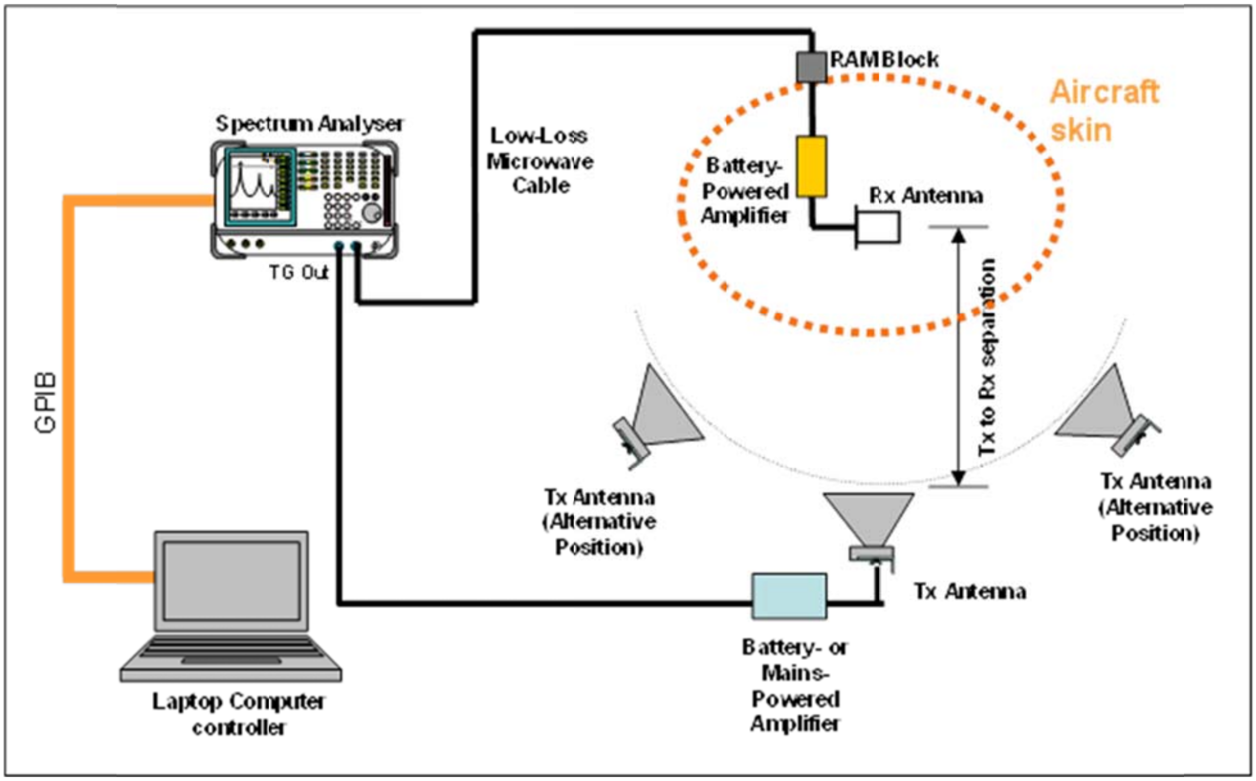

Figure 7 – LLSF Test Set-up Schematic

3.13 Typical figures associated with LLSF measurements are shown in Table 4. The last two columns show the approximate field at the aircraft location 10 m from transmit antenna and at a further range of 100 m from the transmit antenna.

Freq	Sweep Time	TG level	Amp Gain	Cable Loss	Ant Base Power		Ant Gain	EiRP	ERP		Freq Steps	Field @ 10m	Field @ 100m
GHz	ms	dBm	dB	dB	dBm	W	dBi	dBm	dBm	W		V/m	V/m
0.1	140	+5	0	1.80	3.20	0.002	0.00	3.20	1.05	0.001	501	0.020	0.002
1				4.70	0.30	0.001	6.00	0.30	-1.85	0.001		0.014	0.001
1	140	0	29	4.70	24.30	0.27	8.00	32.30	30.15	1.035	501	0.557	0.056
8				11.84	17.16	0.05		25.16	23.01	0.200		0.245	0.024
8	140	+5	27	11.84	20.16	0.10	12.50	32.66	30.51	1.125	501	0.581	0.058
18				16.94	15.06	0.03		27.56	25.41	0.348		0.323	0.032

Table 4 – Typical LLSF Transmission Parameters

3.14 For the calibration stage, which is performed prior to placing the aircraft on the test site, all transmission parameters are as above. The receive antenna is placed in the center of the test site and the field generated by each transmit antenna is measured in turn.

3.15 The receive antenna is then placed within the aircraft bay or area under test employing the same physical equipment and the same transmission parameters, the measurement is repeated and the difference between the two figures is the attenuation provided by the aircraft structure/shell.

3.16 Once each test location has been illuminated from all required aspect angles and both polarizations all the figures for that location are combined and the ‘worst case’ figure (i.e. the lowest ‘worst case’ attenuation) is determined for each frequency.

3.17 The resulting data can then be used to calculate the target environment at each frequency to determine the field that would be experienced at that location if the aircraft was subjected to that threat environment.

3.18 This final figure is then compared to the field strength used during the bench-level radiated susceptibility testing of the relevant system.

4 List of Abbreviations

CW	Continuous Wave
DEW	Directed Energy Weapons
EMC	Electromagnetic Compatibility
E3	Electromagnetic Environmental Effects
FOL	Fiber-optic Link
GHz	Giga Hertz
HF	High Frequency
LLSC	Low Level Swept Current
LLSF	Low Level Swept Field
MHz	Mega Hertz
N0N	Emission Designator for Continuous Wave (CW)
PCB	Printed Circuit Board
RF	Radio Frequency
UHF	Ultra High Frequency
UKAS	United Kingdom Accreditation Service
VHF	Very High Frequency