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Description of NDB and ADF Operation and Definition of Protection Requirements.

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1.0 Introduction

Non Directional Beacons (NDBs) and the associated Automatic Direction Finder (ADF) avionics are widely used to support en-route navigation and airport approach procedures. Appendix A gives a list of the currently operational NDB sites in the UK, along with a map showing their distribution. They are planned for use as an aid to general and commercial aviation navigation for many years to come. It is important therefore that the accuracy, integrity and availability of those systems are maintained to the levels defined in the appropriate standards. As part of ensuring that the standards are met, the systems must be protected from unwanted interference.

One potential source of such interference within the NDB frequency range is the Asymmetric Digital Subscriber Line (ADSL). ADSL is a transmission technology that is planned to deliver broadband services across the existing copper telephony infrastructure. Although this is a wired system, a by-product is energy radiated from the lines, the amount of which is largely dependent upon the balance and quality of the wire. The Civil Aviation Authority (CAA) has raised a concern that the radiation has the potential to adversely affect, or even deny, ADF operation.

The purpose of this paper is to explain how NDB / ADF works, to clearly specify what international standards apply to these systems, and to assist with the definition of practical trials to measure ADSL radiation.

2.0 The Basic Principles of NDB and ADF Operation

2.1 NDB

2.1.1 Applicable Standards

The specification for NDB operation is given in ICAO Annex 10 Volume I, Chapter 3.4 [Ref 1].

2.1.2 Description of Operation

The non directional beacon is an MF transmitter which radiates an uninterrupted carrier in the range 255kHz to 526.5kHz. The carrier is amplitude modulated by a tone of either 400Hz or 1020Hz which is used to key a two or three letter morse identifier. The ident is transmitted at a rate of between 1 and 7 times per minute depending upon the procedure which the beacon is supporting. After tuning to a particular NDB, the pilot uses the audible ident as a confirmation that the correct beacon has been selected.

The frequency management of NDBs is specified in ICAO Annex 10 Volume V, Chapter 3.2 [Ref 2] and was also briefed in the paper produced by the CAA [Ref 3] which was presented at the UK Radiocommunications Agency DSL/PLT Working Group meeting in February 2000. NDB frequency management is based upon the concept of rated coverage. Rated coverage is defined as "the area surrounding an NDB within which the strength of the vertical field of the ground wave exceeds the minimum value specified for the geographical area in which the radio beacon is situated.". For the UK, the minimum desired field strength is **70 μV/m**, which is specified in the ITU Radio Regulations Appendix S12. Furthermore, a protection ratio against interference of 15dB throughout its service area is required for each beacon.

The definition of rated coverage is intended to establish a method of rating beacons on the normal coverage to be expected in the absence of sky wave transmission and/or anomalous propagation from the radio beacon concerned or interference from other LF/MF facilities, but it does take into account the atmospheric noise in the geographical area concerned.

2.2 ADF

2.2.1 Applicable Standards

Whilst there are several international standards and specifications applicable to ADF equipment, the operational requirements are consistent. Within Europe, the EUROCAE document ED-51 [Ref 4] specifies performance requirements, whilst in the US the RTCA document DO-179 [Ref 5] gives the minimum operational performance standards. The only difference between these documents is the requirement for 0.5kHz tuning resolution in Europe.

In the US, ADF equipment should comply with the Technical Standard Order TSO-C41, the current issue of which is ‘d’. The TSO is an extensive document which defines standards for environmental factors, quality, testing etc. However, the minimum performance criteria for ADF are exactly the same as those within RTCA document DO-179.

All radio equipment installed in civil aircraft registered in the UK must be of a type approved by the CAA in relation to the purpose for which it is to be used. The minimum performance requirements for Type Approval are given in the CAA document CAP-208 [Ref 6]. Once again, the requirements are compatible with those of the EUROCAE document ED-54.

Since there is commonality between all of these ADF standards, hereafter within this report ED-54 shall be referred to as the specification.

2.2.2 Description of Operation

The ADF is a form of ‘radio compass’ that provides the pilot with the relative bearing of the beacon to which the equipment is tuned. On the ADF instrument in the cockpit, the needle points towards the selected beacon, enabling the pilot to fly the required procedure. Typical procedures in which NDBs are used are in approaches to airfields and keeping track when flying en-route. In addition, when signals from two beacons can be received, the pilot can calculate his position, known as obtaining a fix.

The ADF works by using the electromagnetic properties of the signal produced by the beacon. Two antennae are required, which are known as the loop antenna and the sense antenna.

The Loop Antenna:

The loop antenna can be simplistically described as two insulated coils of wire wound perpendicular to each other onto a ferrite core. The bi-directional antenna is horizontally polarized, and couples with the magnetic component of the beacon signal. The maximum voltage is induced when the antenna coil is perpendicular to the transmitter. As the antenna pattern contains two nulls, it cannot determine whether the signal is from the 0° or 180° position, hence the need for the sense antenna.

The Sense Antenna:

In its basic form, this can be a long wire antenna, often seen mounted from the aircraft cabin roof to the tail fin. For more modern types of antennae, both loop and sense are located in the same teardrop-shaped housing, mounted as near to the aircraft centreline as possible. This omnidirectional capacitive antenna couples with the electric component of the signal.

The Composite Effect:

In a typical ADF receiver, the signals received by the loop and sense antennae are combined to create the equivalent of a cardioid pattern, as shown in Figure 1.

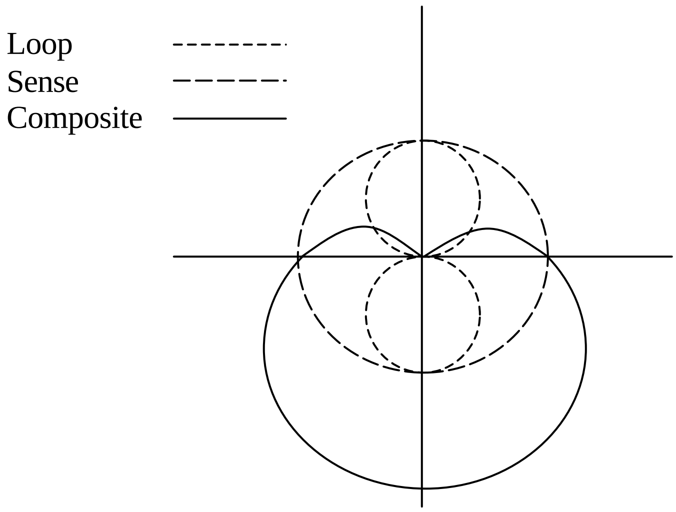

Figure 1 – ADF Antenna Patterns

As is often the case, the resultant signal null is more discrete than the maximum zone. Therefore, the ADF equipment can be positively and accurately tuned to the null. The ADF electronically and/or mechanically aligns the null with the transmitter station by rotating a goniometer. If the goniometer coil is not exactly in the null, a loop voltage will be generated which is applied to a bi-phase motor which rotates the goniometer until it is in the null. Since the phase of the loop antenna signal either leads or lags that of the sense antenna depending upon which side of the null the rotor is positioned, the goniometer can be rotated in the correct direction to achieve the null.

The output from the goniometer is then used to drive the needle on the ADF display in the cockpit.

3.0 Protection Requirements

One of the main objectives of this paper is to define the protection requirements for ADF equipment against interference from sources such as ADSL systems. To enable this, an assumption about the performance of ADF must be made. The assumption is that the ADF equipment is manufactured to meet the performance requirements of ED-54 and not to exceed them. This is a very reasonable assumption to make since significant cost and effort would be required to manufacture the equipment to a higher specification. Whilst it is accepted that there may be some models of ADF which exceed the minimum performance criteria, the majority of models will be at or around the criteria.

The most pertinent performance requirement of ED-54 when considering the effects of ADSL is that for ADF Receiver Selectivity.

Receiver Selectivity

The following is taken directly from ED-51:

"The change in indicated bearing shall not exceed 3 degrees when an undesired signal from a source 90 degrees to that of the desired signal differs in frequency from and exceeds in field strength that of the desired signal by the following amounts:"

Frequency (kHz)	RF Level (dB)
0	-15
± 1	-10
± 1.5	-4
± 2	+2
± 3	+17
± 4	+32
± 5	+47
± 6	+62
± 7	greater than +70

Table 1

Therefore, in order to allow the ADF accuracy requirement to be met, the signal strength of one on-frequency un-desired signal that is at 90° to the desired signal must be at least 15dB below the desired signal strength.

The minimum desired field strength in which the ADF is specified to operate is 70µV/m, (i.e. 37dBµV/m). Therefore, the maximum allowable field strength at the ADF antenna from any single source of on-frequency un-desired signal at 90° to the desired signal is 22**dB**m**V/m)**. Field strengths greater than this could cause the accuracy of the ADF to fall below acceptable levels.

4.0 The Effect of ADSL

ADSL is considered to be a distributed source and always present, which uses frequencies across the NDB band. It can be assumed therefore that there will always be at least one on-frequency un-desired signal at 90° to that of the desired signal to which the ADF is tuned.

However, because ADSL is distributed in frequency and geographically, it is likely that there will be many on and off frequency un-desired signals arriving at the ADF antenna from all angles and with varying signal strength. It is the cumulative effect of all of those signals, and their effect upon ADF, which needs to be determined. Theoretical studies to date have predicted that the cumulative effect at an airborne platform from cabled transmissions could be significant, [Ref 7].

Since the ED-51 requirements shown above in Table 1 define the un-desired signal as a single source, it is important that the cumulative ADSL signal can be described in terms that will facilitate comparison. The effect upon ADF from the cumulative ADSL signal could then be predicted. It should be recognised that it will only be possible to specify meaningful protection requirements once the cumulative effect has been determined.

5.0 The Way Forward

It is important that studies and/or practical trials are undertaken to quantify the ADSL signal that could be present at an ADF receiver. That would enable a radiation limit to be set for ADSL transmission line emissions that would protect NDB / ADF operation.

6.0 References

1. "International Standards and Recommended Practices - Aeronautical Telecommunications - Annex 10 to the Convention on International Civil Aviation. Volume 1 (Radio Navigation Aids)"
   International Civil Aviation Organisation (ICAO)
   5th Edition of Volume 1 - July 1996

2. "International Standards and Recommended Practices - Aeronautical Telecommunications - Annex 10 to the Convention on International Civil Aviation. Volume 5 (Aeronautical Radio Frequency Spectrum Utilisation)"
   International Civil Aviation Organisation (ICAO)
   1st Edition of Volume 5 - July 1996

3. "Clarification of Aeronautical Radiobeacon Protection Criteria and Consideration of the Radiation Limits Proposed in MPT 1570."
   Civil Aviation Authority
   Ref: 8AP/88/08/04 - February 2000

4. "Minimum Performance Specification for Airborne Automatic Direction Finding Equipment."
   European Organisation for Civil Aviation Electronics (EUROCAE)
   ED-51 October 1983

5. "Minimum Operational Performance Standards for Automatic Direction Finding (ADF) Equipment."
Radio Technical Commission for Aeronautics (RTCA)
DO-179 May 1982

6. "Aircraft Radio Equipment."
CAP 208. Volume 1: Minimum Performance Requirements
Civil Aviation Authority

7. "Protection of 'Sensitive' Receiving Sites - Paper for RA Working Group on HF Mains Signalling."
Jonathan Stott, BBC
October 1999

Appendix A – Operational NDB Sites in the UK.

En-Route NDB Facilities:

Name	Ident	Frequency (kHz)	Coordinates	Range (nm)
Burnham	BUR	421.0	513108N 0004038W	15 to 30
Chiltern	CHT	277.0	513723N 0003107W	25
Epsom	EPM	316.0	511910N 0002219W	25
Henton	HEN	433.5	514535N 0004725W	30
Lichfield	LIC	545.0	524448N 0014310W	50
New Galloway	NGY	399.0	551039N 0041007W	35
Scotstown Head	SHD	383.0	573333N 0014902W	25 to 80
Talla	TLA	363.0	553010N 0032550W	25
Westcott	WCO	335.0	515111N 0005745W	30
Whitegate	WHI	368.5	531106N 0023723W	25
Woodley	WOD	352.0	512710N 0005244W	25

Aerodrome and Heliport NDB Facilities:

Name (N=NDB, L=Locator)	Ident	Frequency (kHz)	Coordinates	Range (nm)
Aberdeen/Dyce (L)	ATF	348.0	570439N 0020620W	25
Aberdeen/Dyce (N)	AQ	336.0	570818N 0022417W	15
Alderney (L)	ALD	383.0	494231N 0021158W	30
Barra (N)	BRR	316.0	570132N 0072656W	15
Belfast Aldergrove (L)	OY	332.0	544133N 0060507W	15
Belfast City (L)	HB	420.0	543655N 0055255W	15
Bembridge (N)	IW	426.0	504049N 0010616W	15
Birmingham (L)	BHX	406.0	522716N 0014508W	25
Blackbushe (N)	BLK	328.0	511923N 0005041W	15
Blackpool (L)	BPL	420.0	534622N 0030140W	15
Bourn (N)	BOU	391.5	521239N 0000244W	15
Bournemouth (L)	BIA	339.0	504639N 0015032W	20
Bristol (L)	BRI	380.0	512249N 0024258W	25
Brough (N)	BV	372.0	534331N 0003453W	15
Caernarfon (N)	CAE	320.0	530600N 0042024W	15
Cambridge (L)	CAM	332.5	521239N 0001058E	15
Cardiff (L)	CDF	388.5	512335N 0032017W	20
Carlisle (L)	CL	328.0	545625N 0024819W	20
Compton Abbas (N)	COM	349.5	505759N 0020913W	10
Coventry (L)	CT	363.5	522439N 0012421W	20
Cranfield (L)	CIT	850.0	520747N 0003325W	15
Cumbernauld (N)	CBN	374.0	555832N 0035829W	25
Dundee (L)	DND	394.0	562718N 0030653W	25
East Midlands (L)	EMW	393.0	524943N 0012715W	10

East Midlands (L)	EME	353.5	524957N 0011140W	20
Edinburgh (L)	UW	368.0	555418N 0033009W	25
Edinburgh (L)	EDN	341.0	555842N 0031707W	35
Enniskillen (N)	EKN	357.5	542339N 0073836W	15
Exeter (L)	WX	337.0	504507N 0031742W	15
Fairoaks (N)	FOS	348.0	512047N 0003350W	8
Fenland (N)	FNL	401.0	524430N 0000139W	15
Fife (N)	GO	402.0	561057N 0031312W	15
Filton (L)	OF	325.0	513118N 0023524W	25
Glasgow (L)	AC	325.0	554850N 0043233W	25
Glasgow (L)	GLG	350.0	555527N 0042009W	15
Gloucestershire (L)	GST	331.0	515331N 0021004W	25
Guernsey (L)	GRB	361.0	492603N 0023756W	30
Haverfordwest (N)	HAV	328.0	514956N 0045806W	10
Hawarden (L)	HAW	340.0	531045N 0025846W	25
Humberside (L)	KIM	365.0	533425N 0002112W	15
Islay (N)	LAY	395.0	554058N 0061457W	20
Isle of Man (L)	RWY	359.0	540510N 0043630W	20
Isle of Man (N)	CAR	366.5	540828N 0042930W	25
Jersey (L)	JW	329.0	491221N 0021311W	25
Kirkwall (L)	KW	395.0	585734N 0025441W	40
Lashenden (N)	LSH	340.0	510917N 0003853E	15
Leeds/Bradford (L)	LBA	402.5	535153N 0013910W	25
Leicester (N)	LE	385.3	523623N 0010206W	10
Lerwick/Tingwall (N)	TL	376.0	601118N 0011447W	25
Liverpool (L)	LPL	349.5	532022N 0024330W	25
London/City (N)	LCY	322.0	513016N 0000403E	10
London Gatwick (L)	GY	365.0	510750N 0001857W	15
London Gatwick (N)	GE	338.0	510951N 0000408W	15
London Heathrow (L)	HRW	424.0	512843N 0002733W	20
London Luton (L)	LUT	345.0	515340N 0001509W	20
London Stansted (N)	SSD	429.0	515341N 0001442E	20
Londonderry (L)	EGT	328.5	550243N 0070918W	25
Lydd (N)	LYX	397.0	505816N 0005712E	15
Manchester/Barton (N)	BAE	325.0	532809N 0022319W	10
Manchester (L)	MCH	428.0	532111N 0021622W	15
Manston (L)	MTN	347.0	512027N 0012046E	20
Newcastle (L)	NEW	352.0	550301N 0013833W	40
Newcastle (L)	WZ	416.0	550024N 0014825W	10
Northampton/Sywell(N)	NN	378.5	521757N 0004749W	15
Norwich (L)	NH	371.5	524035N 0012304E	20
Norwich (L)	NWI	342.5	524039N 0011729E	20
Nottingham (N)	NOT	430.0	525518N 0010446W	10
Oxford/Kidlington (L)	OX	367.5	514956N 0011923W	25
Penzance Heliport (N)	PH	333.0	500742N 0053104W	15
Plymouth (L)	PY	396.5	502524N 0040644W	20
Prestwick (L)	PW	426.0	553239N 0044053W	15
Prestwick (N)	PIK	355.0	553022N 0043438W	15
Redhill (N)	RDL	343.0	511258N 0000820W	10
Rochester (N)	RCH	369.0	512114N 0003013E	10

Scatsta (L)	SS	315.5	602734N 0011255W	25
Scilly Isle/St Mary's (L)	STM	321.0	495451N 0061728W	15
Sheffield City (L)	SMF	333.0	532333N 0012259W	15
Sherburn-in-Elmet (N)	SBL	323.0	534722N 0011230W	10
Shipdham (N)	SDM	348.5	523725N 0005530E	10
Shobdon (N)	SH	426.0	521441N 0025233W	20
Shoreham (L)	SHM	332.0	505008N 0001744W	10
Sleap (N)	SLP	382.0	525001N 0024604W	10
Southampton (L)	EAS	391.5	505718N 0012122W	15
Southend (L)	SND	362.5	513433N 0004200E	20
Stornoway (L)	SAY	431.0	581250N 0061934W	60
Sumburgh (L)	SBH	351.0	595256N 0011741W	25
Swansea (L)	SWN	320.5	513608N 0040357W	15
Tatenhill (N)	TNL	327.0	524853N 0014600W	10
Teeside (L)	TD	347.5	543337N 0012000W	25
Warton (N)	WTN	337.0	534505N 0025108W	15
Welshpool (N)	WPL	323.0	523748N 0030914W	10
Wick (L)	WIK	344.0	582648N 0030347W	30
Woodford (L)	WFD	380.0	532015N 0020930W	15
Yeovil/Westland (L)	YVL	343.0	505629N 0023952W	20