Aeronautical Radio Communication Systems and Networks

Dale Stacey
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Dale Stacey

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You may ask why I wrote this book. There are many, many personal reasons as with any author I suppose. The first two reasons and probably the most important are my love of flying and my love of radio engineering. This may sound rather dull but I love flying in any machine be it balloon, glider, propeller aircraft, microlight through to airline jets and the experience of it. The more I do it the more I feel I understand it.

A relative once asked me, ‘how does an aircraft fly?’ I thought for a while, of how to try and explain the fundamentals of physics and aerodynamics which I feel privileged to have had a fundamental education in. After further thought I realized how I take it all for granted like the vast majority of the people, and despite this education and the sound engineering principles, I still find that flying defies all our instinct and it truly is difficult to explain.

I also find the whole topic of radio propagation equally magical. Again, how can it work when we cannot see it? How can signals travel through apparent nothingness. How can we predict it? The physical equations are all there to describe it in great detail, however it too defies a layman’s logic.

If we now marry these two topics together we get Aeronautical Radio Communications—the discipline. This concept is maybe also hard to grasp for most of us and I include myself in this. Writing this book has been a journey of self-discovery and actually showed to myself how much I do not know about the subject rather than how much I know, but hopefully going through this motion has enabled me to know where to look for information when I do not have it to hand.

On the engineering level, some of the system building blocks described may seem very primitive and out of date, especially the legacy aspects, but on another level they are proven to be effective and reliable and this prerequisite knowledge is a fundamental requirement when moving to the design and implementation of the next generation of equipment. There is also the added dimension of thinking about the users of the systems who have a vital role in defining the architecture.

Over the years I have set about collecting the information basis for how the separate aeronautical and radio systems work and I kept them in a file with all the equations I ever used. With time this has grown and initially I have built courses for radio engineers and aviators alike; however, I always planned to put all this information in one tidy place. This is an attempt to do exactly this. It was always my intention to clean up the notes I had and formalize them somehow—hence this book.

I do not pretend that this book has everything on mobile radio communications in it or everything to do with aeronautical mobile radio; however, hopefully it provides the basis for much of
it and some explanation, guidance and direction to where further reading material may be available. It is also not intended to be the end of the subject. This topic is continually growing, adapting and getting updated and I have attempted to capture this in the most up-to-date snapshot.

If you do find discrepancies or changes, I would appreciate any comments or information you equally can share with me. In the interim, I hope it provides you with good background in the knowledge you seek.

You can contact me on dale.stacey@consultacom.com

Happy reading!

Dedications

To my wife Mary and two little angels Caitlin and Isla, thank you for your sacrifices of my family time and your support to write this book.

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About the Author

Since graduating from the University of Bath in the United Kingdom in 1988 with a BSc (Hons) degree in Electrical and Electronic Engineering and becoming a Chartered Engineer in the United Kingdom in 1991 and Australia in 1993, Dale Stacey has worked extensively as a Radio Systems Engineer and Project Manager in many arenas all over the world. For the last 15 plus years of which he has been consulting.

Projects have included feasibility studies, planning and design work, installation and commissioning, project management, operation/maintenance and network management of systems. Technologies have included microwave radio links, VHF/UHF mobile systems, GSM 3G, WiMAX and private mobile systems, VSAT satellite systems.

Assignments have included work with oil companies, utility and PTT companies, mining companies, mobile operators, banks, equipment manufacturers and computer network providers, Internet service providers (ISPs) and federal and local government departments in mainly Australia, Asia, North America and Europe.

More recently projects have concentrated on radio systems used in the aviation industry. The author has consulted and worked with Eurocontrol, ICAO, IATA, various government administrations, air navigation service providers (ANSPs) and aeronautical organizations and companies internationally.

The author has dual Australian/British citizenship and spends his time flying around these continents playing with radios as one would expect.
The author derives a living from his consultancy services and teaching in radio engineering, particularly aeronautical mobile radio. More information on training and consultancy services can be found at www.consultacom.com, or you can send an email to dale.stacey@consultacom.com.

Revisions, Corrections, Updates, Liability

I would strongly appreciate feedback as to the content, correctness and ongoing relevance to each of the sections in this book, topics that need deeper elaboration or new topics that should be incorporated. I promise to read all comments and include them as necessary in any future updates. I do believe that this is the best process for improvement. Substantial contributions on your part will be rewarded with a current or future copy of the book and acknowledgement.

Whilst trying to uphold the greatest professionalism obliged by the professional institutions I believe in and belong to, I have endeavoured to provide accurate and unambiguous information. It is hoped that with review and subsequent editions the material can be continually improved. Your help is appreciated in this process.

Book Layout and Structure

The following chapters are generally laid out in a chronological order so the reader can skip parts depending on their subject knowledge or interest. In addition to this there is a matrix layout separating theory (Section A) and practice (Section C) with an intermediate layer called system level (Section B) which bridges the gap between theory and practice describing the various building blocks. Thus to a degree the topics are repeated three times with the emphasis changing from theory, system building blocks to practical realizations, so the reader can go back to first principles at any time or concentrate on the system level or physical realizations.

Where content does not sit logically with any of these main sections, special appendices have been compiled, in particular for a summation of all the formulae, list of variables, list of acronyms, constant and unit conversions, etc.
1 Introduction

1.1 The Legacy

The start of the new millennium marks two special centenaries: 100 years of manned flights since the Wright brothers flew the first ever manned heavier than air flight (a total distance of a few hundred feet in December 1903) and also 100 years since the first successful long-distance radio transmissions by Marconi at the end of the Nineteenth century and for the first time across the Atlantic in 1902.

Both of these inventions have revolutionized the world. In many ways the revolutions have only just begun. In the field of aviation, we have seen Concorde and travel to space in the last 50 years. Flying for leisure, the start of Space Tourism and even proposed intercontinental rocket services are perceivable in the not too distant future. Star Wars is the reality!

Likewise, in radio there are revolutions going on in the field of personal communications, in much more recent times with individual mobile phones being the norm and usually incorporating new advanced data services, TV media and video all in one small unit that slips into the back pocket. This as such has replaced what a whole office typing pool, mainframe computer and broadcasting house once did and the threat is even more progress: evolution and even revolution with the next generation of intelligent, cognitive and software radio. This is perceived and technically feasible but still really waiting to happen.

The changes in the aviation industry are arguably more conservative and have been slower than the personal communications revolution. The first radio communications were pioneered in the 1920s with tangible on-board transceivers emerging between the war years and with the main standards and practices in aeronautical VHF communications emerging in the late 1940s. These have, arguably, not significantly changed since then. This has been mainly due to very robust and proven systems (for example, the mainstay VHF communication system is testimony to this) that have served us well and is also due to the airlines’ reluctance to undergo the time- and cost-intensive process of re-equipping and change (Figure 1.1).

1.2 Today and the Second Generation of Equipment

Today, there is a requirement to enhance the legacy of mobile communication services to provide the users with more functionality, flexibility, immunity to interference (both RF and
Figure 1.1 Evolution of aeronautical mobile radio systems.
malicious) and reliability. To an extent, this is already well underway by introducing datalink services such as ACARS and VHF datalink and aeronautical satellite services as a second generation stop gap. The ‘stop gap’ should be emphasized. As with many of these systems, the engineering has been ‘shoe-horned’ into existing spectrum allocations or using proprietary technologies almost in experimental conditions. Whilst this has bought time, the solutions are not optimized for technology, application and spectrum efficiency and are all the time aging and becoming less relevant.

1.3 The Future

The technology is already ripe for the next (third) generation of communication systems in aviation and the unit cost of this equipment is ever decreasing. The next years will see some decisive changes in aeronautical communications being driven by the availability of this technology and also by the congestion and shortfalls in the legacy systems which are becoming more exaggerated and exasperating every day. Also it is clear that a rationalization of all the systems is required to simplify long term equipage. In contrast, we should not forget our terrestrial mobile communications counterparts (public mobile services) which have already realized much of their third-generation systems and are already planning for fourth- and even fifth-generation systems. Aeronautical communications lag in this deployment but have the advantage to be able to benefit from their experience and even plagiarizing their technology lessons and development work by effectively purchasing plain off-the-shelf modular radio equipment based on these standards. Of course, aviation also has analogous requirements to these other industry sectors transposed to fractionally different scenarios.

1.4 Operational and User Changes

It should never be forgotten that the operational aspects are ever changing, with an emphasis on increased safety statistics, reduced delays for aircraft in all phases from ground turn around, en route and approach stacking, and for greater automation, i.e. less work load on individual air traffic controllers. The user requirements are fast changing from the legacy of system we have from postwar times to fully computerized systems with redundancy provisions.

The customer market profile has totally changed. From the middle of the Nineteenth century and arguably still till the 1980s and 1990s, aircraft transport was historically only available to the upper class and business elite. Today, it very much competes with cars and trains and in some cases has become cheaper than the cost of leaving your car at or getting to the airport. The consequential change in demand has been exponential. In addition, this has changed the airline market profile and drastically the aircraft density; in given air volumes and airports this in turn impacts on operational changes.

The civilian fleets are constantly changing and getting bigger with an emphasis on capacity throughput in high-density sectors – hence, for example, the new Airbus A380. The economic model looks to increase fuel-burn efficiency with litres per passenger mile being the benchmark to improve upon.

There is a growing requirement and commitment to using unmanned aerial vehicles (UAVs) in civilian as well as military airspaces, which place a whole new operating concept and requirement on the aeronautical communications systems.

There is a greater need for data interactions between aircraft and ground and for other aircraft to bring in some new navigational and surveillance concepts such as free routes flying (where aircraft adopt a trajectory of least distance akin to great circle routes, instead of the traditional air corridors still used today).
Also, in automatic dependent surveillance (ADS) pilots will attain greater local traffic awareness and responsibility from regularly up-linking adjacent aircraft positions. There is also a strategy to move to greater automated air traffic control, fully computerized with intervention by exception or under conflict only. A new communication system will enable the move to these more efficient operations. This will become critical in the immediate future as fuel prices continue to rise and impact the very fragile economic business cases of the airlines.

### 1.5 Radio Spectrum Used by Aviation

Figures 1.2 and 1.3 in their broadest senses depict the radio spectrum used by aeronautical communications today.

The subject matter of most interest is probably the VHF communication band, HF band and satellite bands, but the future communications bands should also be stressed, which could likely be VHF (108–137 MHz), L band (960–1215 MHz), S band (2.7–3.1 GHz) and C band (5.000–5.250 GHz) or a hybrid of these. Today, these are only partly defined but will be ratified in the aeronautical agendas planned for the next World Radio Conferences in 2007 and 2011.

Also shown in the figures are adjacent allocations to navigation and surveillance functions and some of the lesser known obscure allocations to specialist services. This figure is generic and applied on a worldwide basis as per the aviation requirement; however, it should be noted that there are some slight regional and individual sovereign state allocation variations that are not discussed here (for a fuller discussion see ITU Radio Regulations, http://www.itu.org).

---

**Figure 1.2** Communications radionavigation and surveillance bands.
### Frequency vs. Wavelength

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Hz</td>
<td>ELF</td>
</tr>
<tr>
<td>30 Hz</td>
<td>SLF</td>
</tr>
<tr>
<td>300 Hz</td>
<td>ULF</td>
</tr>
<tr>
<td>3 kHz</td>
<td>VLF</td>
</tr>
<tr>
<td>30 kHz</td>
<td>LF</td>
</tr>
<tr>
<td>300 kHz</td>
<td>MF</td>
</tr>
<tr>
<td>3 MHz</td>
<td>HF</td>
</tr>
<tr>
<td>30 MHz</td>
<td>VHF</td>
</tr>
<tr>
<td>300 MHz</td>
<td>UHF</td>
</tr>
<tr>
<td>3 GHz</td>
<td>SHF</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 000 km</td>
</tr>
<tr>
<td>10 000 km</td>
</tr>
<tr>
<td>1000 km</td>
</tr>
<tr>
<td>100 m</td>
</tr>
<tr>
<td>10 m</td>
</tr>
<tr>
<td>1 m</td>
</tr>
<tr>
<td>10 cm</td>
</tr>
<tr>
<td>1 cm</td>
</tr>
</tbody>
</table>

### Communications (conventional civil)

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF Mobile</td>
<td>2.85–23.35 MHz</td>
</tr>
<tr>
<td>SINCGARS</td>
<td>225–400 MHz</td>
</tr>
<tr>
<td>JTIDS/MIDS</td>
<td>960–1215 MHz</td>
</tr>
<tr>
<td>AMS(R)S Satellite comms</td>
<td>1544–1555 MHz</td>
</tr>
</tbody>
</table>

### Radio Navigation

<table>
<thead>
<tr>
<th>System</th>
<th>Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>LORAN-C</td>
<td>90–10 kHz</td>
</tr>
<tr>
<td>LOHAVA</td>
<td>1.8–2 kHz</td>
</tr>
<tr>
<td>VOR ILS Localiser Beacon</td>
<td>108–117.975 MHz</td>
</tr>
<tr>
<td>ILS Glide Beacon</td>
<td>328.6–335.4 MHz</td>
</tr>
<tr>
<td>DME</td>
<td>90–1215 MHz</td>
</tr>
<tr>
<td>MLS</td>
<td>3–15.25 GHz</td>
</tr>
</tbody>
</table>

### Surveillance

<table>
<thead>
<tr>
<th>System</th>
<th>Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSR/ACAS</td>
<td>1030 and 1090 MHz</td>
</tr>
<tr>
<td>Primary Radar</td>
<td>2.7–3.1 GHz</td>
</tr>
<tr>
<td>Airborne weather Radar</td>
<td>3.35–5.47 GHz</td>
</tr>
<tr>
<td>Airborne Doppler radar</td>
<td>8.75–8.85 GHz and 13.25–13.4 GHz</td>
</tr>
<tr>
<td>ASDR</td>
<td>15.4–15.7 GHz, 24.25–24.65 GHz, and 31.8–33.4 GHz</td>
</tr>
<tr>
<td>Precision approach/ASDR radar</td>
<td>9–9.5 GHz</td>
</tr>
</tbody>
</table>

**Figure 1.3** Aeronautical radio spectrum.
1.5.1 Convergence, Spectrum Sharing

The concept of convergence is worth mentioning at this stage as well. Historically, separate allocations have been made for the communication, navigation and surveillance functions (sometimes denoted as CNS) for aviation services as defined in ITU. With the spectrum resource being a limited commodity, there has been a growing tendency and impetus towards sharing radio spectra between radio services. This trend is set to continue but also with seeing a merging of these traditional CNS applications to share the same band. These trends somewhat complicate the business of spectrum allocation, sharing and protection from harmful interference. This will be discussed later.

1.6 Discussion of the Organizational Structure of Aviation Communications Disciplines

Finally, by way of an introduction, it is important to mention some of the important stakeholders in the aviation arena (Figure 1.4). Apologies are made in advance if this list is incomplete and it is in no particular order. It is an attempt to capture the relationships.

Figure 1.4 Aviation-related organizations.
1.6.1 International Bodies

The International Civil Aviation Organization (ICAO) (see www.icao.int) was formed in December 1944 to provide guidance for setting up standards and recommended practices for the civil airline industry, to promote safety, to help facilitate international air navigation and to harmonize the international regulatory scene.

The International Air Transport Association (IATA) (see www.iata.org) in its own words ‘represents, leads and serves the airline industry’; its membership consists of the majority of world airlines. Complete listing of airline membership is on their web page.

The North Atlantic Treaty Organization (NATO), (see www.nato.int) is an international body among other things responsible for harmonizing and organizing the military aspects of aviation in the north Atlantic Europe and America and coordinating with its civilian counterpart (ICAO).

Eurocontrol (see www.eurocontrol.int) is a European wide body responsible for the harmonization and safety of European skies in its ‘one sky for Europe’ policy.

1.6.2 Example National Bodies

In each country, there are regulatory bodies governing the legal and regulatory aspects of flight within that state. For example, in the United States there is the Federal Aviation Administration (FAA) (see www.faa.gov), in France there is the Direction Générale de l’Aviation Civile (DGAC) (see www.dgac.fr), in the United Kingdom there is the UK Civil Aviation Authority (CAA) (see www.caa.co.uk), and these organizations are generally reflected in each state. The Joint Aviation Authority (JAA) (see www.jaa.org) is partially a European and North American wide representation of the CAA, concentrating on airworthiness, safety aspects and harmonizing of CAA goals.

Also in each sovereign state there is generally an Air Navigation Service Provider; in the United Kingdom, for example, this is National Air Traffic Services (NATS) (see www.nats.co.uk), in Switzerland it is Skyguide (see www.skyguide.ch), in Germany Deutsche Flugsicherung (DFS) (see www.dfs.de).

1.6.3 Industrial Interests

Examples include manufacturers such as Airbus (see www.airbus.com), Boeing (see www.boeing.com), Bombardier (see www.bombardier.com), etc. (Their suppliers and associated aerospace industries are not listed here.)

1.6.4 Example Standards Bodies and Professional Engineering Bodies

There are also a handful of standardizations bodies; some of them of relevance to this book include the following:

- Aeronautical Radio Incorporated (ARINC) (see www.arinc.com);
- European Organisation for Civil Aviation Equipment (EUROCAE) (see www.eurocae.org);
- Radio Technical Commission for Aeronautics (RTCA) (www.rtca.org);
- Airlines Electronic Engineering Committee (AEEC);
- European Telecommunications Standards Institute (ETSI) (www.etsi.org);
1.6.5 Users/Operators

As well as IATA already mentioned, some of the other user groups include the following:

- International Federation of Air Traffic Controllers Associations (IFATCA) (see www.ifatca.org);
- Aircraft Owners and Pilots Association (AOPA) (see www.aopa.org), sometimes called General Aviation;
- Airline Pilots Association (ALPA) (see www.alpa.org).

Again, this is only the start of a list and some of the major players.