Technical Handbook
for
Radio Monitoring

VHF/UHF

Edition 2013

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Description of modulation techniques
and waveforms on VHF/UHF
with 232 pictures and 85 tables

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Oscar Diez

Disclaimer:

The information in this book have been collected over years. The main problem is that there are not many open sources to get information about this sensitive field. Although we tried to verify these information from different sources it may be that there are mistakes. Please do not hesitate to contact us if you discover any wrong description.

Content

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3. General

The “Technical Handbook for Radio Monitoring HF” is meanwhile well known and used by many radio listeners (official or private) worldwide.

Due to the high amount of systems we decided to separate the description of signals in the VHF/UHF range from those heard on HF.

This book has been written to help the listener in identifying the different modes or waveforms which are active throughout the VHF/UHF band.

It will never be complete.

But it will give a good overview which techniques are state of the art today. It has to be mentioned that most of the pictures are a result of the decoder HOKA CODE 300-32 and PROCITEC PROCEED. For the wide band spectra we have used an AOR5000 with SDR-14 or PERSEUS on the IF-frequency of 10.7 MHz.

This book is divided in four main parts:

- Basic information about modulation
- Waveforms used on VHF/UHF
- Tables for Radio Monitoirng
- Abbreviations and Index

The part basic information is giving an overview about common modulation techniques with a short description and how they look like in the spectrum or phase plane display. This part also describes standard expressions from the field of coding, error correction and so on which are often used in the field of radio communication.

The following section describes most of the waveforms which can be heard on VHF and UHF.

The book is finished with some helpful tables taken from th HF edition, the abbreviation table and index.

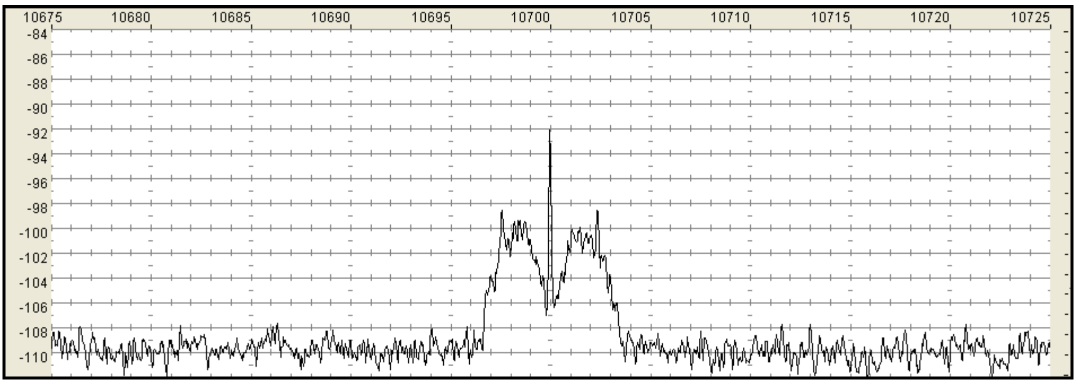
5. VHF Modes

ACARS

Aircraft Communications Addressing and Reporting System

ACARS (Aircraft Communications Addressing and Reporting System) is a 2400 bps MSK packet-like system used by Civilian Aircraft for onboard flight-deck computer interconnections into ground stations. The centre frequency is on 1800 Hz and a shift of 1200 Hz is used. It is a NRZI coded coherent audio frequency MSK and an AM carrier to use standard AM communication equipment.

The spectrum and sonagram of ACARS is shown in the following pictures:



Picture 52: Spectrum of ACARS

Picture 53: Sonagram of ACARS packets

ACARS is mainly transmitted in the VHF range. The following frequencies are assigned to ACARS:

Frequency in MHz	Mode	Used in:
129.125	ACARS	Additional channel for USA & Canada
130.025	ACARS	Secondary channel for USA and Canada
130.425	ACARS	Additional channel for USA
130.450	ACARS	Additional channel for USA & Canada
131.125	ACARS	Additional channel for USA
131.450	ACARS	Primary channel for Japan
131.475	ACARS	Air Canada company channel
131.525	ACARS	European Channel
131.550	ACARS	Primary Channel for USA and Canada Also Primary Channel for Australia
131.725	ACARS	Primary channel in Europe
131.825	ACARS	Additional European Channel
131.850	ACARS	Additional European Channel
136.700	ACARS	Additional channel for USA
136.725	VDL4	European Channel
136,750	ACARS	Additional European Channel Additional channel for USA
136.775	VDL4	European Channel
136.800	ACARS	Additional channel for USA
136.825	ACARS	European Channel

Frequency in MHz	Mode	Used in:
	ARINC VDL2	
136.850	ACARS	SITA North American Channel
136.875	VDL2	European Channel
136.900.	ACARS SITA	Additional European Channel
136.925	ACARS ARINC	ARINC European Channel
136.950	Exp VDL4	European Channel
136.975	VDL2	European Channel

Table 14: Main ACARS frequencies

As with all high-speed MSK systems, subsequent demodulation is very sensitive to inter-symbol interference.

Each message frame consists of at least 50, and up to a maximum of 272 characters or bytes. Each character uses a 7 bit ACSII code with an additional eighth parity bit. This results in a total message transmission duration of between 0.17 and 0.91 seconds.

The message frame format is rigidly defined to include synchronization, address, acknowledgment, mode and error checking characters, in addition to the actual message text. Imbedded message label characters indicate the type of message. The exact message format is shown below.

Number of Characters	Purpose	Comment
16	Pre-key	Transmitter warm-up/Rx AGC adjustment
2	Bit sync	Establish bit synchronisation
2	Character sync	Establish character synch
1	SOH	Indicate start of heading
1	Mode	Ground system interface configuration
7	Address	Aircraft registration number
1	Ack/Nak	Acknowledge/non-acknowledge marker
2	Label	Type of message
1	Block ID	Message block number
1	STX	Indicates start of message text
4	Sequence#	Message sequence number
6	Flight number	Airline flight number
210	Text	Message text

Number of Characters	Purpose	Comment
1	ETX	End of text
16	Block Check Seq	Error detection polynomial value
1	BCS	Suffix last character

Table 15: ACARS message format

The sixteen pre-key characters are all binary 1 values, resulting in the 0.05 second 2400 Hz pulse heard at the start of every message. The block check sequence field contains the value of an error detection polynomial that can be used to determine if the entire message was received free of errors.

ADS-B

Automatic Dependent Surveillance – Broadcast, Squitter Mode

Automatic Dependent Surveillance Broadcast (ADS-B) is a technology transmitting aircraft information like position, airspeed, altitude aso. The waveform is a Pulse Position Modulation (PPM) with a data rate of 1 MBps. In a PPM the pulse is transmitted in the first or second half of the bit period indication a 1 or a 0.

There are two types of broadcast from an airplane: the short squitter and the extended squitter (1090ES). The short squitter has a length of 56 Bits and is transmitted once per second.

Control 8 Bit	Aircraft Address 24 Bit	Parity 24 Bit

Picture 54: Mode S short squitter frame

The extended squitter also transmits a 56 bit data field which contains additional information for the ADS-B. The total frame length is 112 bit.

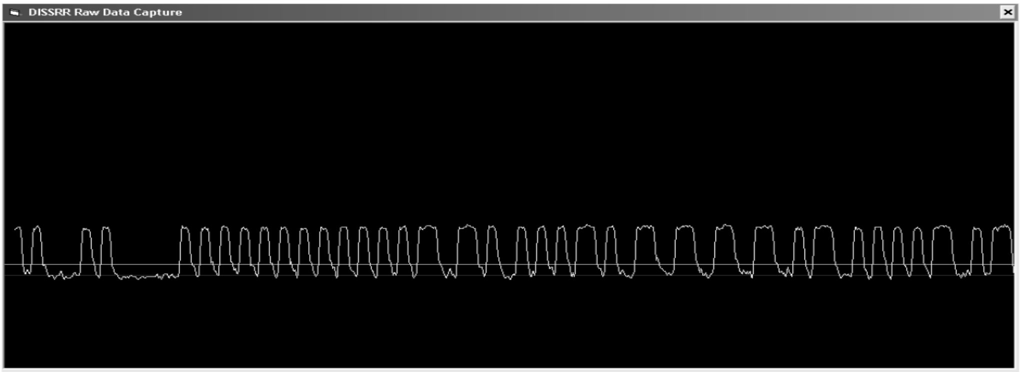
Control 8 Bit	Aircraft Address 24 Bit	ADS Message 56 Bit	Parity 24 Bit

Picture 55: Mode S extended squitter frame

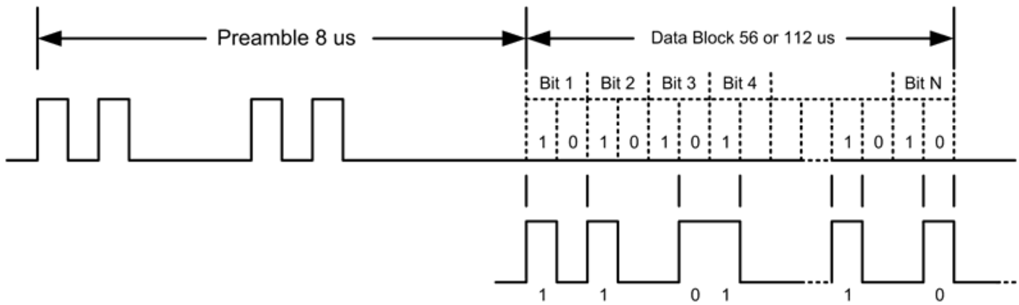
ADS-B is using the satellite based global positioning system to determine an aircraft's precise location in space. The system then converts the position into a digital code, which is combined with other information such as the type of aircraft, speed, flight number, and whether it's turning, climbing, or descending. The digital code, containing all of this information, is updated several times a second and broadcast from the aircraft on a discrete frequency as an extended squitter.

Other aircraft and ground stations within about 150 miles receive the data link broadcasts and can display the information on a monitor. Pilots in the cockpit see the traffic on a Cockpit Display of Traffic Information (CDTI). Controllers on the ground can see the ADS-B targets on their regular traffic display screen, along with other radar targets.

ADS-B is usually transmitted on 1090 MHz in regulary intervals.



Picture 56: PPM of ADS-B



Picture 57: Framing of ADS-B

AIS

Automatic Information System for ships

The AIS transponder works on 161.975 MHz and 162.025 MHz in an autonomous and continuous mode, regardless of whether it is operating in the open seas or coastal or inland areas. Transmissions use 9.6 kb GMSK FM modulation using HDLC packet protocols. The data structure is as follows and consists of 256 bit:

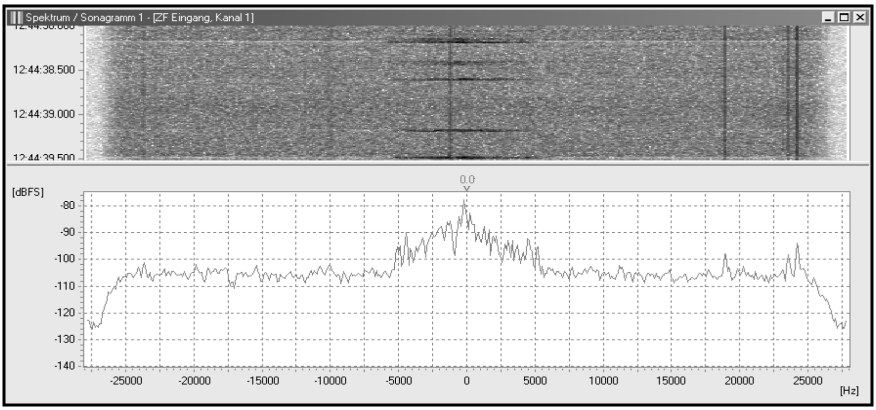
Training Seq	Start Flag	Data	FCS	End Flag	Buffer
24 Bit	8 Bit	168 Bit/Slot	16 Bit	8 Bit	24 Bit

Picture 58: AIS frame

Function	No of Bits	Description
Ramp up	8	
Training sequence	24	Synchronisation
Start Flag	8	HDLC 0x7E
Data	168	
CRC/FCS	16	HDLC
End Flag	8	HDLC 0x7E
Buffering	24	Bit stuffing, distance delay, repeater delay and jitter

Table 16: Data structure of AIS

These information are transmitted within one slot of 26.67 ms.



Picture 59: AIS spectrum and sonogram

Although only one radio channel is necessary, each station transmits and receives over two radio channels to avoid interference problems, and to allow channels to be shifted without communications loss from other ships. The system provides for automatic contention resolution between itself and other stations, and communications integrity is maintained even in overload situations.

Each station determines its own transmission schedule (slot), based upon data link traffic history and knowledge of future actions by other stations. A position report from one AIS station fits into one of 2250 time slots established every 60 seconds. AIS stations continuously synchronize themselves to each other, to avoid overlap of slot transmissions. Slot selection by an AIS station is randomized within a defined interval, and tagged with a random timeout of between 0 and 8 frames. When a station changes its slot assignment, it pre-announces both the new location and the timeout for that location. In this way new stations, including those stations which suddenly come within radio range close to other vessels, will always be received by those vessels.

The required ship reporting capacity according to the IMO performance standard amounts to a minimum of 2000 time slots per minute, though the system provides 4500 time slots per minute. The SOTDMA broadcast mode allows the system to be overloaded by 400 to 500% through sharing of slots, and still provide nearly 100% throughput for ships closer than 8 to 10 NM to each other in a ship to ship mode. In the event of system overload, only targets further away will be subject to drop-out, in order to give preference to nearer targets that are a primary concern to ship operators. In practice, the capacity of the system is nearly unlimited, allowing for a great number of ships to be accommodated at the same time.

The system is backwards compatible with digital selective calling systems, allowing shore-based GMDSS systems to inexpensively establish AIS operating channels and identify and track AIS-equipped vessels, and is intended to fully replace existing DSC-based transponder systems.

A Class A AIS unit broadcasts the following information every 2 to 10 seconds while underway, and every 3 minutes while at anchor at a power level of 12.5 watts. The information broadcast includes:

- MMSI number - unique referenceable identification
- Navigation status (as defined by the COLREGS - not only are "at anchor" and "under way using engine" currently defined, but "not under command" is also currently defined)
- Rate of turn - right or left, 0 to 720 degrees per minute (input from rate-of-turn indicator)
- Speed over ground - 1/10 knot resolution from 0 to 102 knots
- Position accuracy - differential GPS or other and an indication if (Receiver Autonomous Integrity Monitoring) RAIM processing is being used
- Longitude - to 1/10000 minute and Latitude - to 1/10000 minute
- Course over ground - relative to true north to 1/10th degree
- True Heading - 0 to 359 degrees derived from gyro input
- Time stamp - The universal time to nearest second that this information was generated

In addition, the Class A AIS unit broadcasts the following information every 6 minutes:

- MMSI number - same unique identification used above, links the data above to described vessel
- IMO number - unique referenceable identification (related to ship's construction)
- Radio call sign - international call sign assigned to vessel, often used on voice radio
- Name - Name of ship, 20 characters are provided
- Type of ship/cargo - there is a table of possibilities that are available
- Dimensions of ship - to nearest meter
- Location on ship where reference point for position reports is located
- Type of position fixing device - various options from differential GPS to undefined
- Draught of ship - 1/10 meter to 25.5 meters [note "air-draught" is not provided]
- Destination - 20 characters are provided (at Master's discretion)
- Estimated time of Arrival at destination - month, day, hour, and minute in UTC (at Master's discretion)

Types of Automatic Identifications Systems

ITU-R Recommendation M.1371-1 describes the following types of AIS:

Class A

Shipborne mobile equipment intended for vessels meeting the requirements of IMO AIS carriage requirement, and is described above.

Class B

Shipborne mobile equipment provides facilities not necessarily in full accord with IMO AIS carriage requirements. IEC has begun work on a Class B certification standard, which should be completed by 2004 - 2005. The Class B is nearly identical to the Class A, except the Class B:

- Has a reporting rate less than a Class A (e.g. every 30 sec. when under 14 knots, as opposed to every 10 sec. for Class A)
- Does not transmit the vessel's IMO number or call sign
- Does not transmit ETA or destination
- Does not transmit navigational status
- Is only required to receive, not transmit, text safety messages
- Is only required to receive, not transmit, application identifiers (binary messages)
- Does not transmit rate of turn information
- Does not transmit maximum present static draught

Class B devices are not yet available.
These 3 figure codes have been allocated by the International Telecommunications Union (ITU), and are used to denote the country of registration of a vessel or the location of a shore station using DSC. Note that the numbers are issued on a geographic or regional basis. Large nations normally have a vacant block after the main allocation - these vacant blocks are planned to be used for expansion once the main allocation has been used.

AMPS

Advanced Mobile Phone System

Advanced Mobile Phone System (AMPS) is the analogue mobile phone system standard developed by Bell Labs, and officially introduced in the Americas in 1983 and Australia in 1987. It was the primary analogue mobile phone system in North America (and other locales) through the 1980s and into the 2000s. As of February 18, 2008, carriers in the United States were no longer required to support AMPS and companies such as AT&T and Verizon have discontinued this service permanently. AMPS was discontinued in Australia in September 2000.

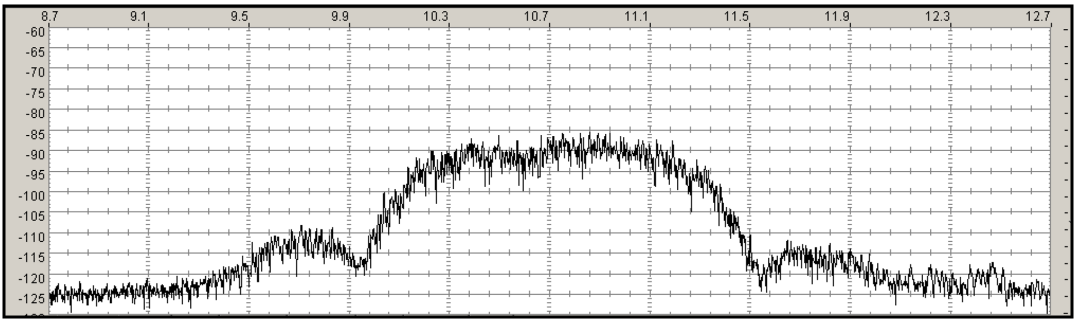
AMPS is a first-generation cellular technology that uses separate frequencies for each conversation. Each channel has a bandwidth of 30 kHz. In AMPS, the cell centers can flexibly assign channels to handsets based on signal strength, allowing the same frequency to be re-used in various locations without interference. This allowed a larger number of phones to be supported over a geographical area.

DECT

Digital European Cordless Telephony

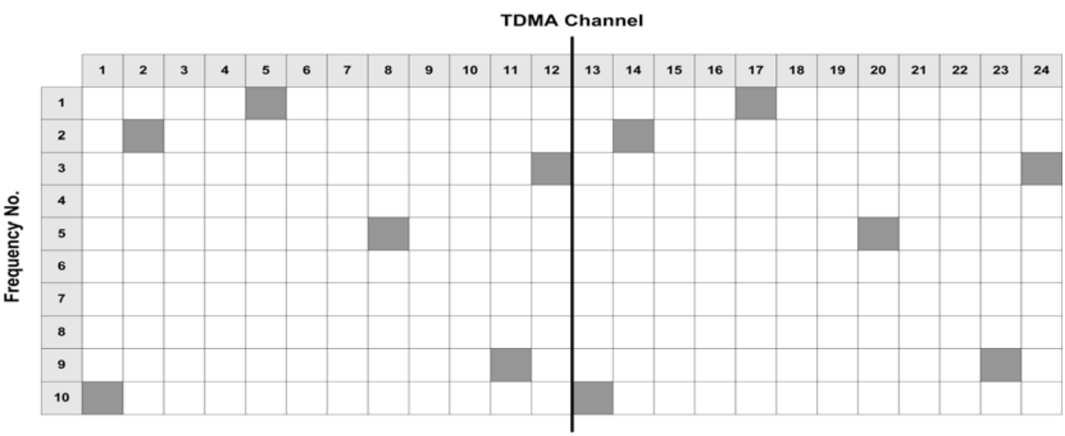
The Digital European Cordless Telephony (DECT) is a standard for the 1885 – 1900 MHz band and has a modulation structure which is similar to GSM.

DECT is using a standard modulation of GFSK. But the DECT specification allows three other modulation schemes: π/2 DBPSK, π/4-DQPSK and π/8-D8PSK. While the first of these modulation schemes is compatible with GFSK, the last two provide 2 and 4 times the data rate as GFSK. This means that, combined with the high speed data profile, data rates of up to 2 Mbps can be achieved using DECT. The spectrum of a DECT signal is shown in the following picture:



Picture 83: Spectrum of a DECT signal

DECT is using a TDD/TDMA structure with a total of 24 frames or time slots. Each frame has a length of 10 ms. The first 12 frames or slots are allocated for the transmission from the base station to the handset. The second part of 12 frames or slots are for the transmission from the handset to the base station. The following pictures shows the this distribution:

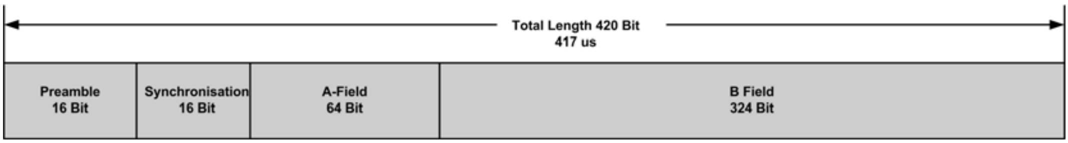


Picture 84: Slot occupation of DECT

DECT is not assigning frequencies or slots to a special handset/base station. The channels are dynamically allocated when setting up a call. But DECT is selecting the channel with the best quality so during a conversation the connection may be transferred to another channel.

The DECT standard allows different slot types which may vary in length. Voice is always transmitted in an unprotected slot with 320 bit of data. Speech is coded with 32 kbps ADPCM.

The framing is as follows:



Picture 85: Framing of DECT voice transmission

In addition to voice, DECT also offers several ways to transmit data using DPRS (DECT Packet Radio Service). This consists of a series of profiles that each allow a particular data service. The DECT data services use the protected B field, which consists of 256 data bits and 68 CRC bits. This increased level of protection that any errors can be resolved using ARQ. Data services can use more than one slot pair per connection, and can use these in symmetric or asymmetric mode. This means that in theory at least, one portable can use 23 slots in one direction, and 1 slot in the reverse direction.

DPMR

Digital Private Mobile Radio, dPMR446

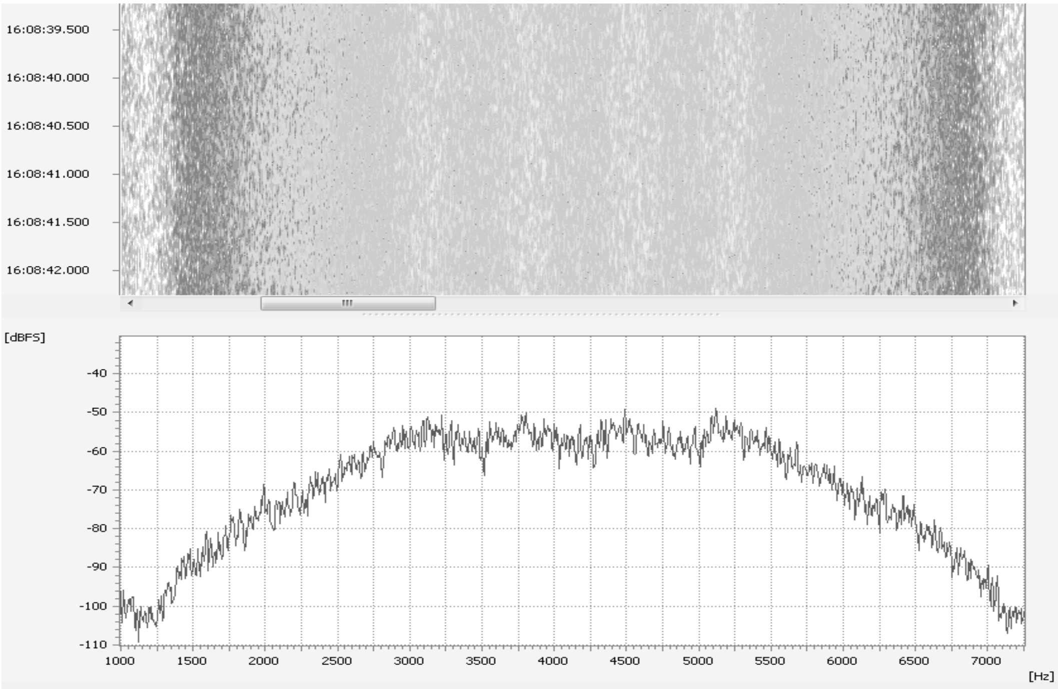
DPMR is using a 4FSK with a symbol rate od 2400 bd which gives a data rate of 4800 bps. The shift between carriers is 700 Hz. The access method is FDMA. For voice transmission the AMBE+2 vocoder is used. The codec rate is 3600 bps, 2450 bit are used for the voice and 1150 bit for error correction. DPMR is using a TDMA with 30 ms frames.

The symbols are mapped according the following table on the four frequencies:

Di-Bit	Symbol	Frequency Shift
01	+1	+ 1050 Hz
00	+1	+ 350 Hz
10	-1	- 350 Hz
11	-3	- 1050 Hz

Table 30: Frequency mapping DPMR

The typical spectrum and sonagram centered on 3125 Hz is shown in the following picture:



Picture 86: Spectrogram of DPMR

It can transfer voice and data. This could be i.e. GPS positions or text messaging.

DPMR is using a bandwith of 6.25 kHz. The maximum power is 500 mW.
DPMR radios are license-free for the use in the 446.100 MHz - 446.200 MHz band within Europe.

DPMR is supporting several modes for operation:

Mode	Descriptions
-	License-free (DPMR 446)
Mode 1	Direct Peer-to-peer Mode
Mode 2	Conventional Repeater Mode
Mode 3	Digital Trunking Mode

Table 31: Modes of DPMR

DPMR Mode 1

This is the peer to peer mode of DPMR. This mode can operate on all PMR frequency bands and has no RF power limits of DPMR.

DPMR Mode 2

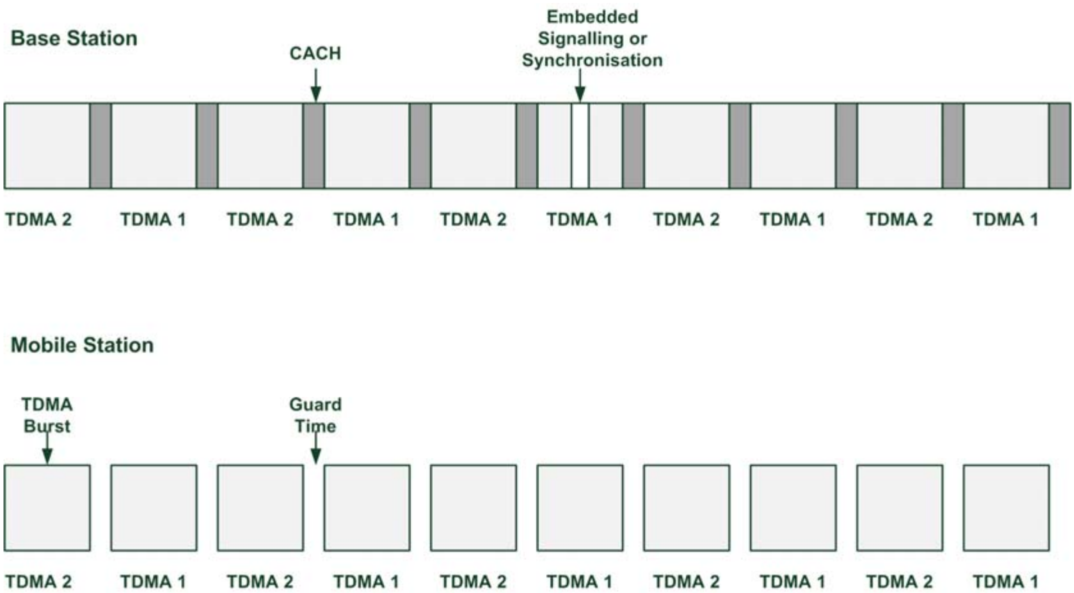
The mode 2 operations includes repeaters and other infrastructure.

DPMR Mode 3

This mode offers multichannel, multisite trunked radio networks. Management of the radio network starts from the authentication of radios that wish to connect. Calls are set-up by the infrastructure when both parties have responded to the call request. Calls may be diverted to other radios, landline numbers or IP addresses. The infrastructure managing these beacon channels would be capable to placing a call to another radio whether that radio is using the same site or another site within the network.

DPMR Framing

DPMR is using a TDMA structure with 2 slots. The general timing for the base station and a mobile station is shown in the next figure.

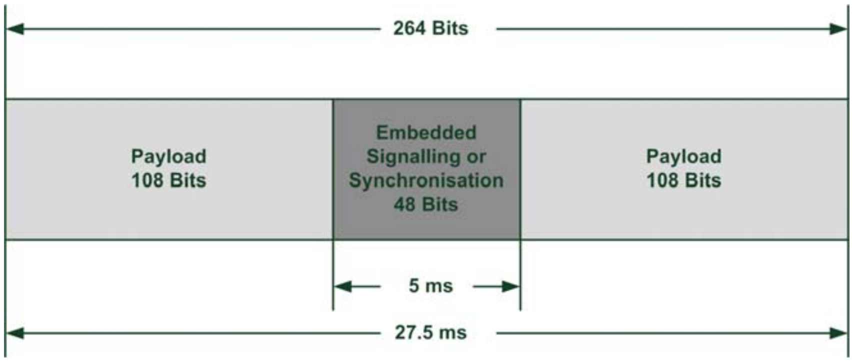


Picture 87: DPMR TDMA structure

Each TDMA burst has a length of 30 ms. Two bursts are forming a TDMA frame of 60 ms. The base station is transmitting a Common Announcement Channel (CACH) between the TDMA bursts. The mobile station is using a guard time between the burst to allow an amplifier ramping and propagation delay. Bursts have either a synchronization pattern or an embedded signalling field located in the center of the burst. Placing the embedded signalling in the middle of a burst allows time for a transmitting MS to optionally transition to the outbound channel and recover Reverse Channel (RC) information.

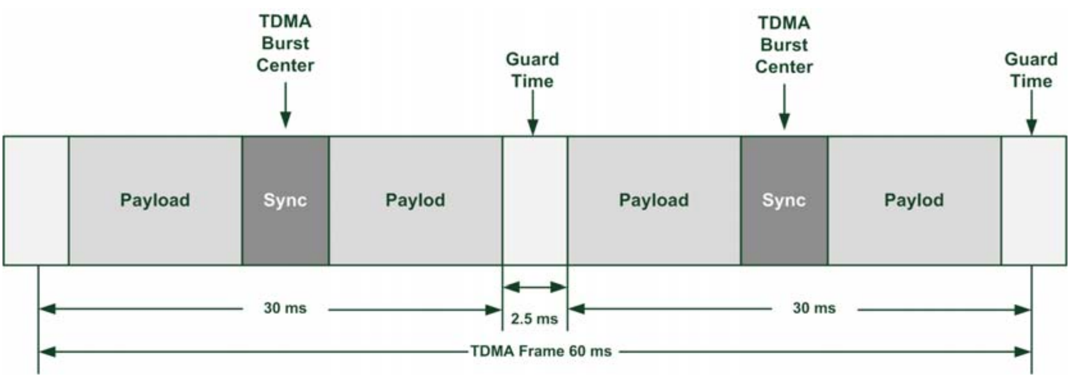
DPMR Burst Structure

The generic burst structure consists of two 108-bit payload fields and a 48-bit synchronization or signalling field as shown in the next figure.



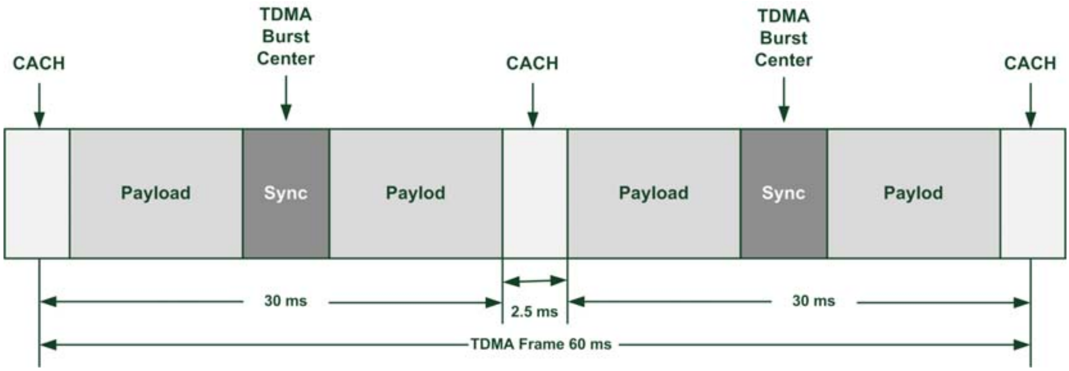
Picture 88: DPMR generic burst structure

Each burst has a total length of 30 ms but 27,5 ms are used for the 264 bits content, which is sufficient to carry 60 ms of compressed speech, using 216 bits payload. For a vocoder that uses 20 ms vocoder frames, the burst will carry three 72-bit vocoder frames (including FEC) plus a 48-bit synchronization word in a voice burst, that is 264 bits (27,5 ms) used for the burst contents. The center of each burst has a field that carries either synchronization or embedded signalling. This field is placed in the middle of a burst to support RC signaling. On the inbound channel, the remaining 2,5 ms is used for guard time to allow for PA ramping and propagation delay, as shown in the next picture for an inbound frame.



Picture 89: DPMR TDMA frame mobile station

On the outbound channel, this 2,5 ms is used for a Common Announcement Channel (CACH) that carries TDMA frame numbering, channel access indicators, and low speed signalling as shown in the next figure for an outbound frame.



Picture 90: DPMR TDMA frame base station

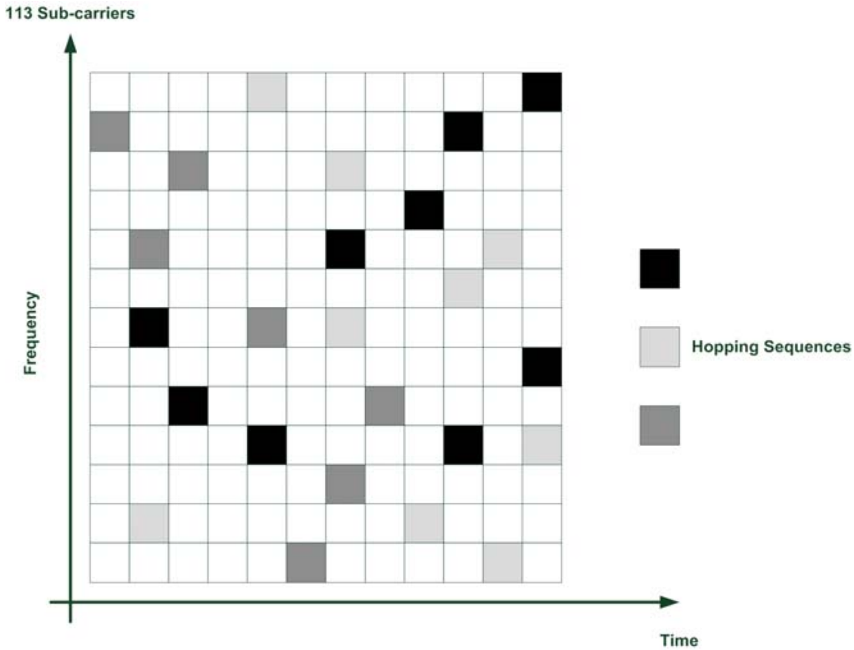
The frame synchchronisation (SYNC) is provided by a special sequence of bits that mark the location of the center of a TDMA burst. Receivers may use a matched filter to achieve initial synchronization, using the output of a matched correlator to initialize the symbol recovery parameters to compensate for frequency and deviation errors as well as determine the center of the burst. Once the receiver is synchronized to a channel, it may use pattern matching to detect the presence of SYNC to verify that the channel is still present and determine the type of SYNC to identify the contents of the burst. Multiple SYNC patterns are used to:

- differentiate voice bursts from data/control bursts and from RC bursts;
- differentiate inbound channels from outbound channels.

To accomplish this, the following SYNC patterns have been defined:

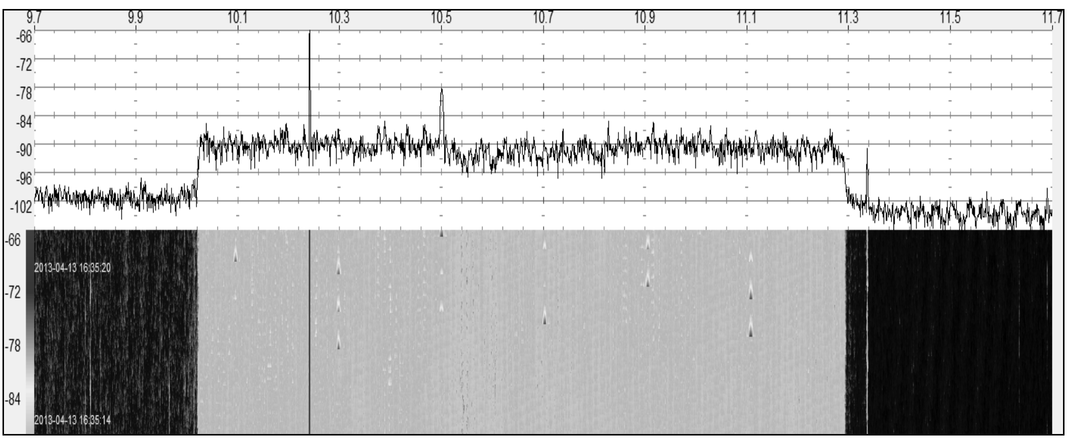
- BS sourced voice;
- BS sourced data;
- MS sourced voice;
- MS sourced data;
- MS sourced standalone RC.

For all two frequency BS channel inbound transmissions and all single frequency channel transmissions, the first burst shall contain a synchronization pattern to allow the target receiver to detect the presence of the signal, achieve bit synchronization, and determine the center of the burst. Follow-on bursts contain either SYNC or embedded signaling depending on the burst type and the context.
For all two frequency BS channel outbound transmissions, it is assumed that the MS is already synchronized to the outbound channel well before the start of any transmissions directed towards it. Therefore, there is no requirement that the voice header shall contain a synchronization pattern.



Picture 171: Principle of FLASH-OFDM

The spectrum of this modulation is shown in the following picture:



Picture 172: Spectrogram of Railnet

This hopping pattern ensures that users within the same cell are allocated orthogonal resources but use a different subcarrier every symbol duration in downlink and every 7 symbol durations in uplink direction. So the users within a cell do not interfere with each other. In FLASH-OFDM 113 carriers with a spacing of 11.25 kHz are used. The symbol rate is 10 KBd. The overall bandwidth is

1.25 MHz and allows a downlink of 3.2 MBps and an upload of 900 kBps. The modulation in the downlink is QPSK, 16QAM, 64 QAM or 256 QAM. In the uplink only QPSK is used.
For a Forward error Correction FEC a vector-LDPC codes with a block length from 1344 to 5248 is used in the downlink. For the uplink the block length is 1344.
In the uplink FLASH-OFDM uses a turbo equalization on a set of 7 QPSK symbols on 7 contiguous OFDM symbols where the 1 symbol is a reference/pilot symbol.

FLASH-OFDM provides high reliability through a link layer that features a fast automatic repeat request (ARQ), which is used to check transmitted data for errors. If an error is found, the message is retransmitted very quickly. Therefore, with loop times at less than 10 milliseconds, FLASH-OFDM ARQ latency is very low. This enables low-latency retransmission of frames received with an error.

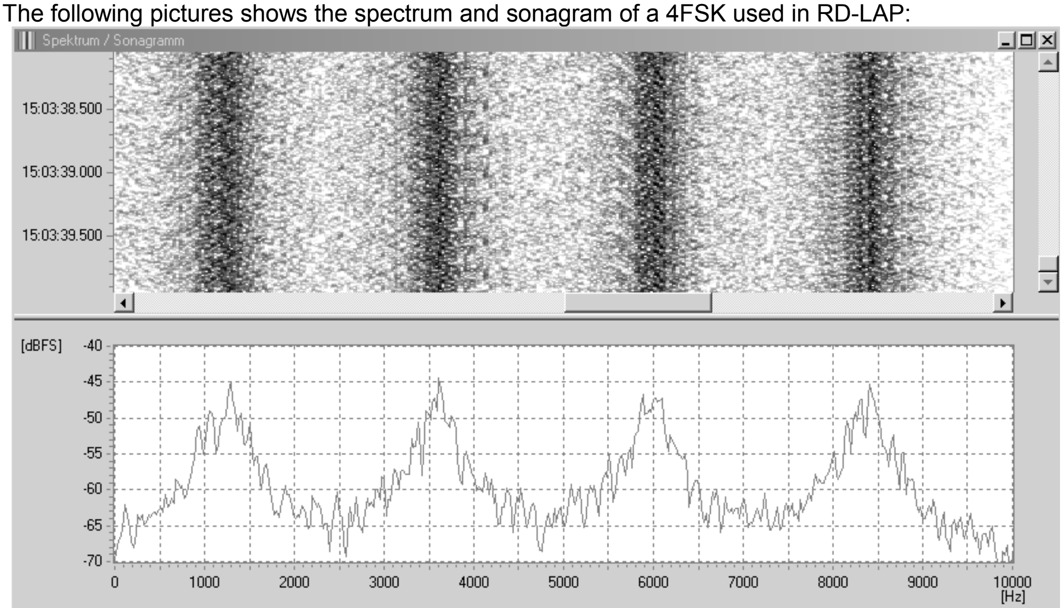
FLASH-OFDM operates in different frequencies like 450MHz, 700MHz, 800MHz, 1.9GHz and 2.1GHz.

RD-LAP

Radio Data Link Access Protocol

RD-LAP is a protocol used i.e. in ARDIS and is using a 4FSK with a shift of 2400 Hz between carriers. The signal is using discrete frequencies of -3600 Hz, -1200 Hz, +1200 Hz and 3600 Hz on the nominal transmission frequency. RD-LAP has a data rate of 19200 Bps and uses FEC and CRC for error correction.

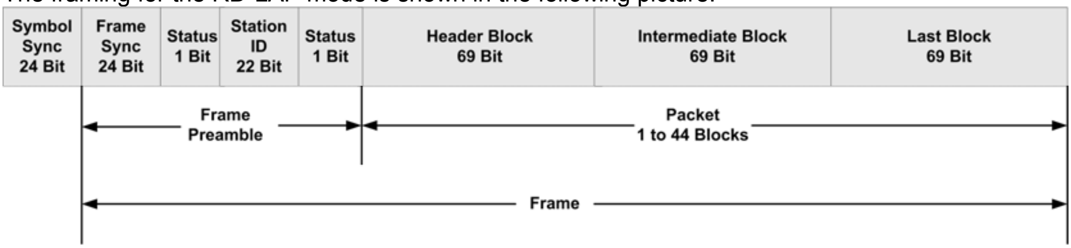
The following pictures shows the spectrum and sonagram of a 4FSK used in RD-LAP:



Picture 173: Spectrum and sonagram of a 4FSK used in RD-LAP

The frame structure in RD-LAP mode consists of a frame preamble (comprising a 24-symbol frame synchronisation pattern and station ID block) followed by one or more'Header’ blocks, one or more 'Intermediate’ blocks and a 'Last’ block. Channel status (S) symbols are included at regular intervals. The first frame of any transmission is preceded by a symbol synchronisation pattern.

The framing for the RD-LAP mode is shown in the following picture:



Picture 174: Framing of RD-LAP

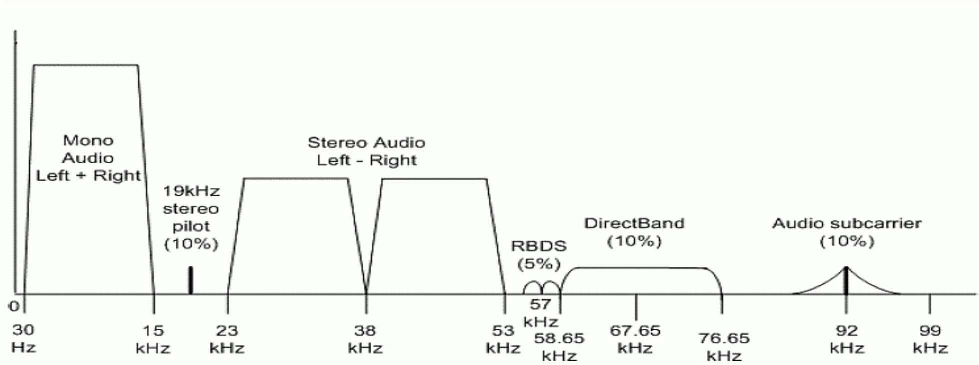
RDS/RBDS

Radio Data System, Radio Broadcast Data System

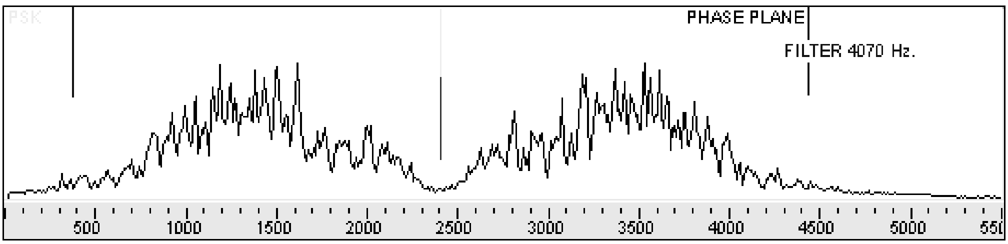
Radio Data System (RDS) is a communications protocol standard from the European Broadcasting Union (EBU) for sending digital information using conventional FM radio broadcasts. The RDS system standardises several types of information transmitted, including time, track/artist info and station identification. RDS is a standard in Europe and Latin America since the early 1990s.

Radio Broadcast Data System (RDBS) is the official name used for the U.S. version of RDS. The two standards are nearly identical. Slight differences are mainly which numbers are assigned to each of the 31 musical and other program formats the RBDS system can identify. RBDS was approved by the NRSC.

RDS and RDBS use a 57kHz subcarrier to carry data at 1187.5 bits per second. The 57 kHz was chosen for being the third harmonic of the pilot tone for FM stereo. This will not cause interference or intermodulation with the pilot tone or with the stereo difference signal at 38 kHz. The data format allows forward error correction (FEC).



Picture 175: Spectrum of FM broadcast carrier

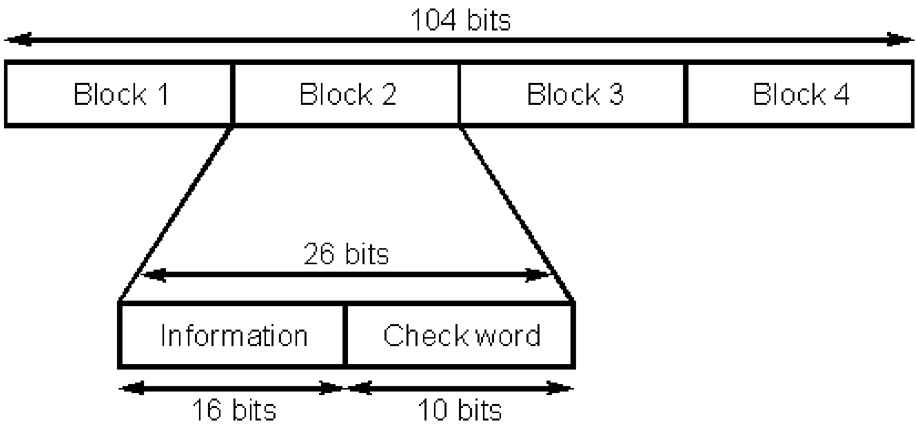


Picture 176: Spectrum of a RDS signal within a WFM signal

RDS is modulated on the subcarrier with a QPSK waveform with a data rate of 1187.5 Bps. This is equal to the frequency of the RDS subcarrier divided by 48.

Data is transmitted in groups consisting of four blocks. Each block contains a 16 bit information word and a 10 bit check word as shown in the next picture. This means that with the data rate of 1187.5 bit per second approximately 11.4 groups can be transmitted each second.

The data groups are structured so that data can be transmitted as efficiently as possible. Different stations will want to transmit different types of data at different times. To cater for this there are a 16 different group structures.
Mixing of different types of data within groups is kept to a minimum. However the coding structure is such that messages which need repeating most frequently normally occupy the same position within groups. For example the first block in a group always contains the PI code and PTY and TP are to be found in block 2.



Picture 177: RDS data structure

RDS data structure

In order that a radio knows how to decode the data correctly, each type of group has to be identified. This function is performed by a four bit code occupying the first four bits in the second block.
Once generated the data is coded onto the subcarrier in a differential format. This allows the data to be decoded correctly whether the signal is inverted or not. When the input data level is "0" the output remains unchanged but when a "1" appears at the input the output changes its state.
With the basic signal generated the spectrum has to be carefully limited. This has to be done to avoid any cross talk in phase locked loop decoders. The power density close to 57 kHz is limited by the encoding each bit as a biphase signal. In addition to this the coded data is passed through a low pass filter.

The following information fields are normally contained in the RDS data:

Alternative Frequencies (AF)

This enables a receiver to re-tune to a different frequency providing the same station when the first signal becomes too weak. This is often utilised in car stereo systems.

Clock Time (CT)

This time can synchronise a clock in the receiver or the main clock in a car. CT can only be accurate to within 100 ms of UTC.

Enhanced Other Networks (EON)

Allows the receiver to monitor other networks or stations for traffic programmes, and automatically temporarily tune to that station.

Programme Identification (PI)

This is the unique code which identifies the station. Each station receives a specific code with a country prefix. In the USA, PI is determined by applying a formula to the station's call sign.

Programme Service (PS)

The programme service is an eight-character static display that represents the call letters or station identity name. Most RDS capable receivers display this information and, if the station is stored in the receiver's presets, will cache this information with the frequency and other details associated with that preset.

Programme Type (PTY)

This coding of up to 31 pre-defined programme types – e.g. (in Europe): PTY1 News, PTY6 Drama, PTY11 Rock music, – allows users to find similar programming by genre. PTY31 seems to be reserved for emergency announcements in the event of natural disasters or other major calamities.

Regional (REG)

This is used in countries where national broadcasters run "region-specific" programming such as regional opt-outs on some of their transmitters. This functionality allows the user to "lock-down" the set to their current region or let the radio tune into other region-specific programming as they move into the other region.

Radio Text (RT)

This function allows a radio station to transmit a 64-character free-form textual information that can be either static e.g. station slogans or in sync with the programming such as the title and artist of the currently-playing song.

Traffic Announcement(TA), Traffic Programme(TP)

The receiver can often be set to pay special attention to this flag and e.g. stop the tape/pause the CD or retune to receive a Traffic bulletin. The TP flag is used to allow the user to find only those stations that regularly broadcast traffic bulletins whereas the TA flag is used to stop the tape or raise the volume during a traffic bulletin.

Traffic Message Channel (TMC)

Digitally encoded traffic information. Not all RDS equipments supports this. Often available for Automotive navigation systems. In many countries only encrypted data is broadcast, and so a subscription and appropriate decoder is required to use.

The following table lists the RDS and RBDS Programm Type codes and their meanings:

PTY code	RDS Programme type (EU)	RBDS Programm type (USA)
0	No programme type or undefined	No program type or undefined
1	News	News
2	Current affairs	Information
3	Information	Sports

PTY code	RDS Programme type (EU)	RBDS Programm type (USA)
4	Sport	Talk
5	Education	Rock
6	Drama	Classic Rock
7	Culture	Adult Hits
8	Science	Soft Rock
9	Varied	Top 40
10	Pop Music	Country
11	Rock Music	Oldies
12	M.O.R. Music	Soft
13	Light classical	Nostalgia
14	Serious classical	Jazz
15	Other Music	Classical
16	Weather	Rhythm and Blues
17	Finance	Soft Rhythm and Blues
18	Children's programmes	Language
19	Social Affairs	Religious Music
20	Religion	Religious Talk
21	Phone In	Personality
22	Travel	Public
23	Leisure	College
24	Jazz Music	Unassigned
25	Country Music	Unassigned
26	National Music	Unassigned
27	Oldies Music	Unassigned
28	Folk Music	Unassigned
29	Documentary	Weather
30	Alarm Test	Emergency Test
31	Alarm	Emergency

Table 59: RDS and RBDS program types

Harris RF 7800V

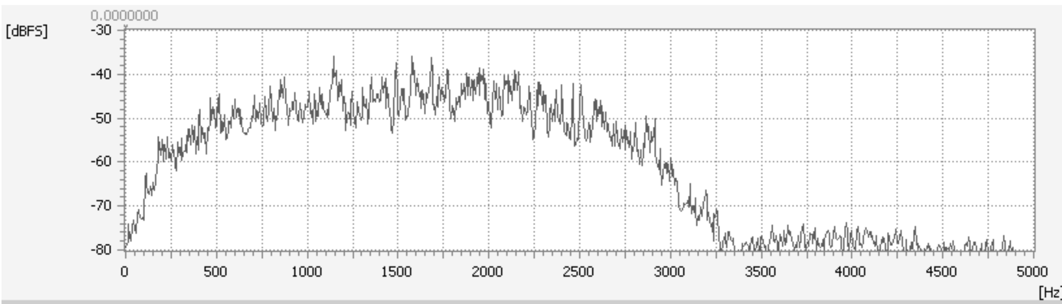
FALCON III

The RF-7800V Combat Net Radio provides continuous coverage in the 30 to 108 MHz frequency band. It is supporting analogue FM, voice transmission with 2400 Bd MELP, secure voice and data with 16 kbd FSK and up to 192 kbps data transmission. For encryption the CITADEL chipset with a 128 bit key is used. During hopping the datarate per hop can be measured with 20 kbd.

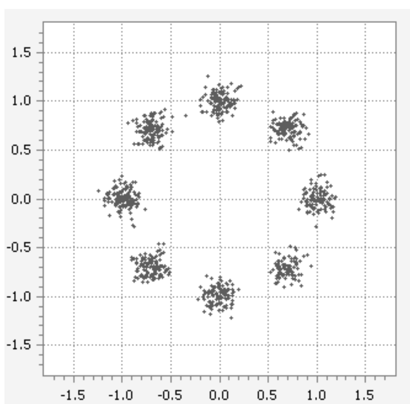
The radio also offers several frequency hopping waveforms Quicklook 1A, Quicklook 2, Quicklook 3 and Quicklook-Wide.

Quicklook-Wide provides 64 kilobits per second of data throughput while frequency hopping.

The following pictures are showing the typical spectrum for a 2400 Bd MELP transmission with 8PSK and the phase constellation.



Picture 178: Spectrum of 2400 Bd MELP signal

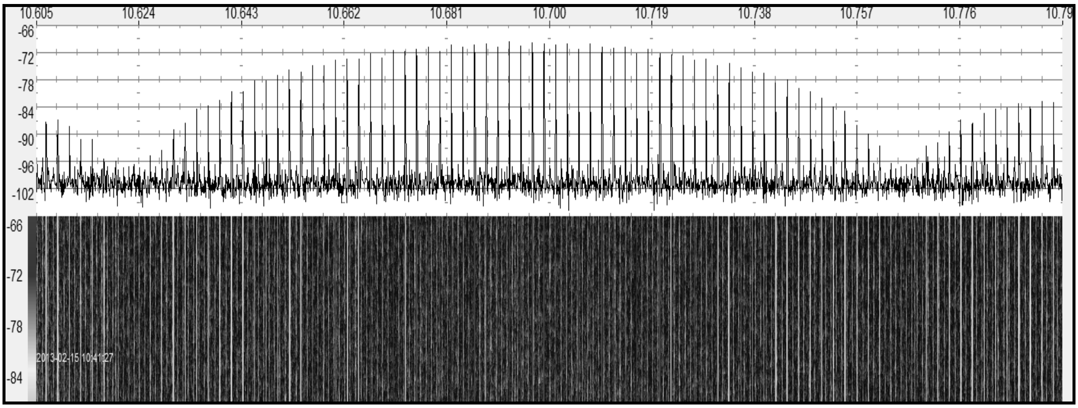


Picture 179: Phase constellation of 2400 Bd MELP signal

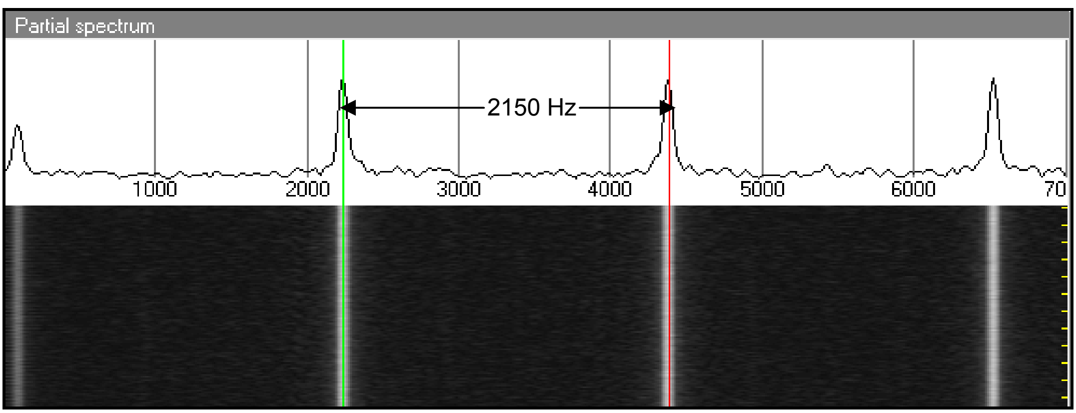
METEOR RADAR

A METEOR RADAR is transmitting short electromagnetic circumpolarly pulses towards the sky. If a meteor strikes Earth's atmosphere at speeds of 100,000 mph or more they ionize the air in their path. These luminous ionized trails reflect radio waves. The meteor echo is received by a reception antenna system and is interferometrically analysed, thus estimating the location, the echo amplitude, and the radial velocity of the ionisation trace moving with the neutral wind. From many of such individual observations i.e. the wind field for an altitude range between about 80 and 110 km can be estimated.

The follwoing pictures where made by receiving the METEOR RADAR at Juliusruh and Kühlungsborn in Northeast Germany. These radars are transmitting on 32.55 MHz and 53.5 MHz. There peak power is 12 KW. The puls width is 13.3 us.



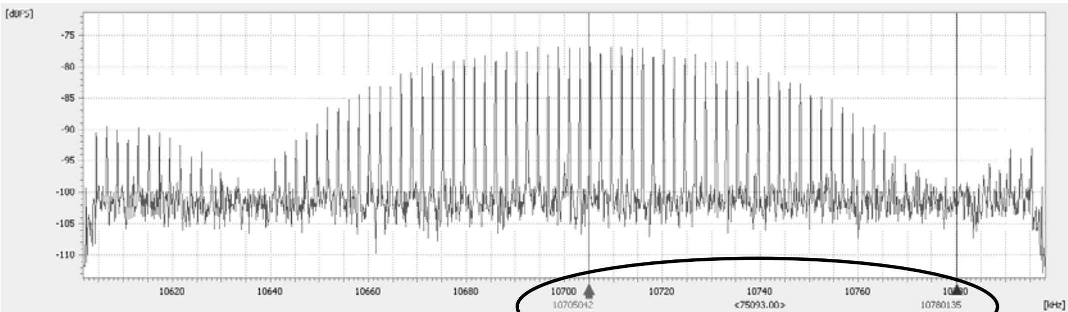
Picture 211: Spectrogram of a METEOR RADAR at Juliusruh on 53.5 MHz



Picture 212: Spectrum of the pulses

Calculating with the frequency distance between two pulse the pulse repetition time is 456 us.

In case of rectangle pulses the pulse width has a direct relation to the shape of the spectrum. By measuring the distance between the center of the signal and the first side minimum the pulse time can be estimated.



Picture 213: Pulse width measurement

The frequency distance is 75093 Hz with results in a pulse time of 13.3 us.

NAVSPASUR

The Air Force Space Surveillance System, also known as the Space Fence, is a multistatic radar system that detects orbital objects passing over the US. It is a component of the US space surveillance network, and is claimed to be able to detect objects as small as 10 cm) at a height up to 30000 km. The headquarter of the surveillance system is located at Dahlgren, Virginia.

There are three transmitter sites in the system:

Location	Frequency	Coordinate
Lake Kickapoo, Texas	216.983 MHz	33°32′47″N 98°45′46″W
Gila River, Arizona	216.970 MHz	33°06′32″N 112°01′45″W
Jordan Lake, Alabama	216.990 MHz	32°39′33″N 86°15′52″W

Table 68: Transmitter locations of NAVSPASUR

The master transmitter is located at Lake Kickapoo and has a CW radiated power of 768 kW.

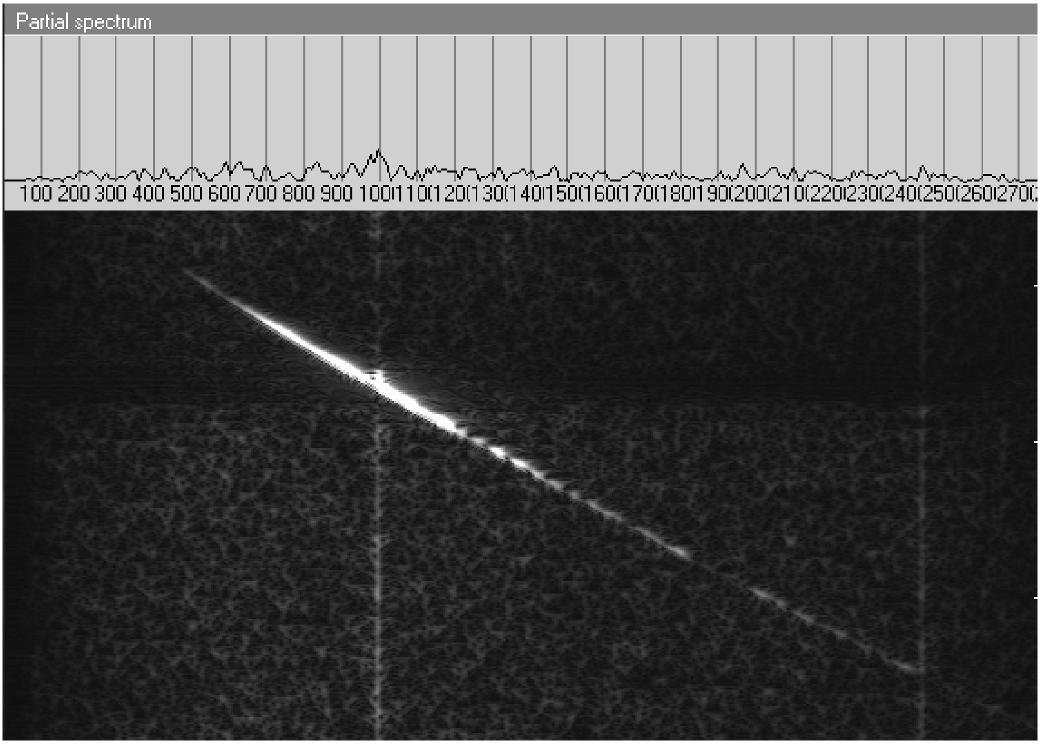
There are 6 receiving stations:

Location	Coordinate
Tattnall, Georgia	32°02′35″N 81°55′21″W
Hawkinsville, Georgia	32°17′20″N 83°32′10″W
Silver Lake, Mississippi	33°08′42″N 91°01′16″W

Red River, Arkansas	33°19′48″N 93°33′01″W
Elephant Butte, New Mexico	33°26′35″N 106°59′50″W
San Diego, California	32°34′42″N 116°58′11″W

Table 69: Receiver locations of NAVSPASUR

A typical reception of an object like a meteor is shown in the following sonagram:



Picture 214: Meteor reception of the NAVSPASUR

7. Satellites

COSPAS-SARSAT

The international COSPAS-SARSAT programme is a satellite-based search and rescue (SAR) distress alert detection and information distribution system, established in 1979.

COSPAS (КОСПАС) is an acronym for the Russian words "Cosmicheskaya Sistema Poiska Avariynyh Sudov" (Космическая Система Поиска Аварийных Судов), which translates to "Space System for the Search of Vessels in Distress". SARSAT is an acronym for Search And Rescue Satellite-Aided Tracking.
The system can detect and locate emergency beacons activated by aircraft or ships. These beacons are transmitting in the 406 MHz range. They are the only ones detected and processed by the system. Signals from the older 121.5 MHz and 243 MHz beacons are not recognized anymore.

The space segment of the COSPAS-SARSAT system consists of SAR signal repeaters (SARR) and SAR signal processors (SARP) aboard satellites:

- 9 geosynchronous satellites called GEOSARs and
- 6 low-earth polar orbit satellites LEOSAR

A SARR/SARP instrument is a small package, that typically is attached to a satellite that is being launched primarily for another purpose.

The six operational LEOSAR satellites (with both SARR and SARP instruments) are the SARSAT satellites provided by the United States NOAA and Europe's EUMETSAT. These orbit at an altitude of approximately 850 km. They are:

- SARSAT -7 instruments aboard NOAA-15
- SARSAT -8 instruments aboard NOAA-16
- SARSAT -9 instruments aboard NOAA-17
- SARSAT -10 instruments aboard NOAA-18
- SARSAT -11 instruments aboard METOP-A
- SARSAT -12 instruments aboard NOAA-19

The GEOSAR satellites provide continuous coverage of the entire earth below about 70 degrees latitude with a view toward the equatorial sky.
Operational SARR are installed on the following six GEOSAR satellites providing continuous coverage of the entire earth below about 70 degrees latitude with a view toward the equatorial sky:

- The GOES satellites (USA) GOES 13 at 75° W and GOES 15 at 135° W
- The INSAT-3A satellite (India) at 93.5° E
- The Meteosat Second Generation (MSG) satellites (Europe) MSG-1 (also known as Meteosat-8) at 9.5° E and MSG-2 (also known as Meteosat-9) fixed over the Prime Meridian.

- The Electro-L No. 1 satellite (Russia) at 76° E.

SARR undergoing testing or in a role as an on-orbit spare are installed on the following geostationary satellites:

- The GOES satellites (USA) GOES 12 at 60° W and GOES 14 at 105° W
- Luch 5A (Russia) at 167° E.
- MSG-3 (EUMETSAT) at 3.4° W.

Typical rescue beacon radios transmit a 5 watt signal for 0.5 second once every 50 seconds. Normally they include a GPS receiver so they can report precise GPS co-ordinates. Aircraft distress radio beacons (ELTs) are automatically activated by g-force switches that detect sudden deceleration during a crash, while maritime radio beacons (EPIRBs) are normally activated by contact with sea water.
The 406 MHz distress radio beacon band is 100 kHz wide. The center frequency is 406.05 MHz. Individual beacons transmit in assigned 3 kHz channels. A transmitted distress message is either a 112-bit "short" message or a 144-bit "long" message, both including 49 bits of identification information. If the beacon has a GNSS receiver or position information derived from another local source (such as ship navigation equipment), then that information also is encoded in the transmitted distress message.

The SARR instrument is transmitting the received signals on 1544.5 MHz.

INMARSAT

***In**ternational **Mar**itime **Sat**ellite Organization*

The INMARSAT system consists of four regions with one satellite for each region according to the following table:

Satellite	Position	Region	NCS Frequency
AOR-E	15.5°W	Atlantic Ocean Region East	1541.45 MHz
IOR	64° W	Indian Ocean Region	1537.10 MHz
POR	178°E	Pacific Ocean Region	1541.45 MHz
AOR-W	53°W	Atlantic Ocean Region West	1537.70 MHz

Table 70: INMARSAT NCS frequencies

All mobile stations (MES) listen in idle mode to the Network Control Station (NCS) common TDM channel which carries signalling information. When a mobile station identifies its id in a signalling frame it will re-act to the commands received from the NCS. In case of a channel assignment message is received it will tune to the assigned transmit-receive frequency pair. The forward telex traffic channel is also TDM with the same frame structure as the NCS TDM containing 22 time slots of 50 Bd telex channels. The telex return channel is a TDMA (Time Division Multiple Access) channel. Voice traffic is FM SCPC (Single Channel Per Carrier). Telex channels are assigned by each earth station and voice channels only by the NCS.

INMARSAT-A

INMARSAT-A was the first service to be introduced, becoming commercially available in 1982. An analogue system, it provides two-way direct-dial phone, fax, telex and electronic mail and data communications at rates of up to 9.6 kilobits per second (kbit/s). Later models make possible high-speed data communications at 56/64 kbit/s. Due to the large size and weight of the INMARSAT-A antenna INMARSAT-A MESs are fitted only on larger ships.

The INMARSAT standard A terminals are grouped into various classes according to their capabilities. These are:

1. Class 1 - Standard A ship earth station usable for both telegraph and telephone type traffic.
2. Class 2 - Standard A ship earth station usable for telephone type traffic and reception of shore-to-ship one way telegraphy.
3. Class 3 - Standard A ship earth station usable for telegraph only traffic.

The forward channel from the NCS is a TDM with 1200 Bd BPSK modulated. For telex traffic also a TDM with 22 * 50 Bd channels is used. For voice traffic in both directions the signal is FM SCPC modulated. The return channel from the Mobile Earth Station (MES) is a 4800 Bd TDMA DBPSK.

INMARSAT Aero H

INMARSAT Aero H service offers voice, fax and data communications from almost anywhere in the sky supporting voice, fax, data and STU-III transmissions at data rates up to 9.6 kbps, 4.8 kbps and 2.4 kbps.

INMARSAT Aero H+

INMARSAT Aero H+ offers voice transmissions at 4.8 kbps, fax at 2.4 kbps and real-time PC modem-based data at 2.4 kbps. In addition, Aero H+ offers cockpit data at speeds up to 1.2 kbps.

INMARSAT Aero I

INMARSAT Aero I service offers digital voice transmission at 4.8 kbps, fax at 2.4 kbps, real-time data at 2.4 kbps and cockpit data at up to 1.2 kbps.

INMARSAT Aero L

INMARSAT Aero L service operates in the INMARSAT global beams and provides aircraft with real-time, low-speed, two-way data communications capability. Aero L is a packet data service designed primarily for aircraft operators who require a highly reliable data communications capability.

INMARSAT Aero Mini-M

INMARSAT Aero Mini-M service offers digital voice, fax and data transmission. The service supports voice transmission up to 4.8 kbps and data or fax transmission up to 2.4 kbps.

INMARSAT-B

The INMARSAT-B system was introduced in 1994 and uses digital technology to provide high quality telephone, fax, telex, e-mail and data communications, with the antenna size and weight being approximately the same as for INMARSAT-A. Like INMARSAT-A, INMARSAT-B is capable of high-speed data communications (at up to 64 kbps), making it especially suitable for data-intensive users such as oil and seismological companies which need to exchange large amounts of data on a regular basis.

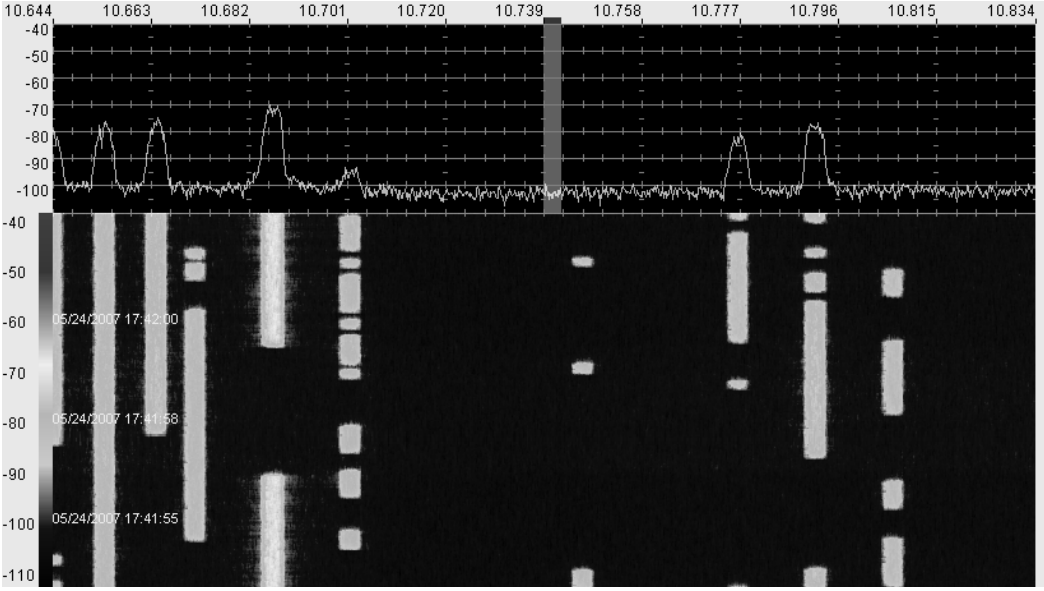
The communications sub-system is based on the use of digital modulation, coding and processing techniques which have been designed to permit efficiency. Filtered quadrature phase shift keying modulation is used on shore to ship carriers with convolutional forward error correction. Ship to shore uses offset QPSK with FEC also. The speech method used for telephony is 16Kbit/s adaptive predictive coding. Other communications services include 56/64Kbit/s data. The APC voice coded is supporting fax up to 2400bit/s.

The forward channel from NCS or LES to the MES are 6 kbps TDM DPSK, 24 kbps OQPSK for voice and low speed data and 132 kbps OQPSK for high speed data. The return channel uses a 24 kbps TDMA OQPSK modulated.

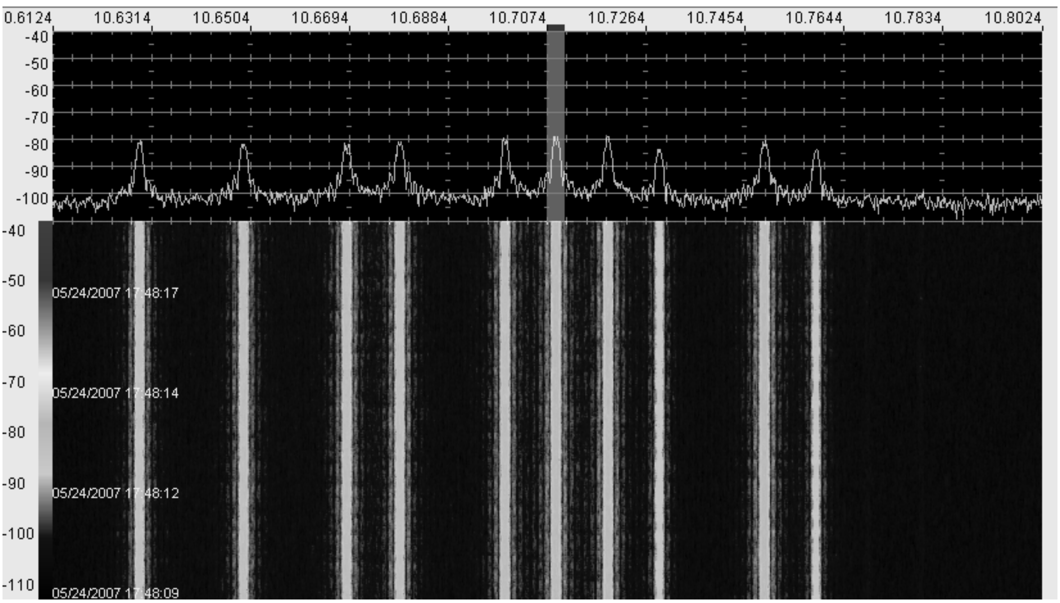
INMARSAT-C

INMARSAT-C was introduced in 1991 to complement INMARSAT-A by providing a global low cost two-way data communications network using a small terminal that could be fitted on either a large or small vessel. Its compactness makes it especially suitable for smaller vessels such as yachts, fishing vessels or supply craft. The INMARSAT-C system does not provide voice communications but is a means of sending text, data and e-mail messages to and from shore-based subscribers using a store-and-forward technique. This requires the user to prepare the message prior to sending it; it is then transmitted via the land earth station operator who sends it on to its intended destination. The global communications capability of the INMARSAT-C system, combined with its Maritime Safety Information (MSI) broadcasts and distress-alerting capabilities, has resulted in the INMARSAT-C system being accepted by the International Maritime Organisation (IMO) as meeting the requirements of the Global Maritime Distress and Safety System (GMDSS). The GMDSS carriage requirements are mandatory for all merchant ships of over 300 Gross Registered Tonnes (GRT) and all passenger vessels which make international voyages.

The following picture shows a typically spectrum of the INMARSAT satellite:



Picture 215: Spectrum of INMARSAT satellite

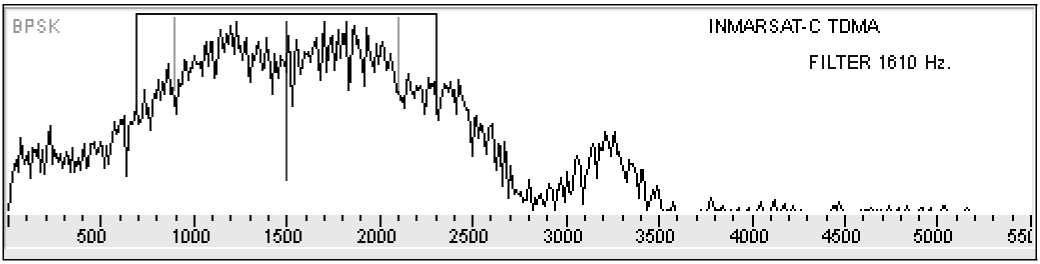


Picture 216: Spectrum of active earth stations on INMARSAT

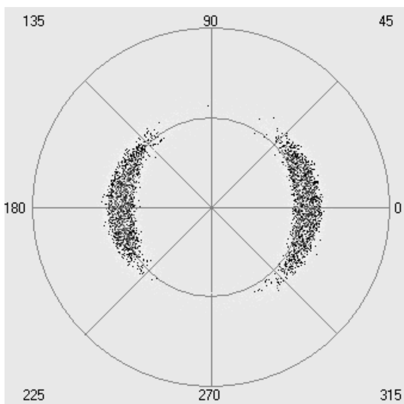
The data rate is 1200 symbols per second modulated in BPSK. This results in a bit rate of 600 Bit/s. Error protection is done by convolutional encoding with R = 1/2 and k = 7. A block or frame of data in the forward direction comprises 10368 symbols (8,64 s). Data is highly interleaved to prevent against slow fading. Additionally scrambling is used to ensure an even distribution of logical 1s and 0s for proper bit synchronization. Frame synchronisation is achieved by using an unscrambled unique word at the beginning of the frame. The coding will correct some errors otherwise ARQ is used.

The forward channels are continuous time division multiplex (TDM) channels. They are used for message transmission and signalling.

In the return direction messages are transmitted by time division multiple access (TDMA) channels assigned by the network control station (NCS). The frame length varies between 2176 symbols and 10368 symbols in steps of 2048 symbols.



Picture 217: Spectrum of INMARSAT-C 1200 Bd TDMA



Picture 218: Phase plane of INMARSAT-C 1200 Bd BPSK TDMA

INMARSAT Mini-C

INMARSAT Mini-C service is an evolution of the existing INMARSAT C technology, combining a transceiver and antenna in one light and compact unit., with the added benefit of a significantly reduced level of power consumption The service offers e-mail, position reporting and polling, fax, telex, short-code addressing and mobile-to-mobile messaging services.

INMARSAT D