AMATEUR RADIO · NOVEMBER 8, 2026

Commercial and Military HF Digital Modes in 2026: HFDL, GMDSS DSC, STANAG 4285, ALE, Link 11, OTH Radar and HF Trading Links

The non-amateur counterpart to the FT8 report. Aviation's HFDL (16 ground stations) is the busiest readable professional mode. Maritime HF has narrowed to DSC, weatherfax, RTTY and PACTOR since NBDP left the GMDSS in 2024.

30 min read · 31 sources

2026 ALE GMDSS HFDL SDR military HF utility monitoring

CONTENTS

How to measure 'popular' when there is no PSKReporter 2
The short list: what you will actually hear 2
- Why the tiers fall this way 3
- Quick reference 3

Aviation: HFDL, the busiest civilian data mode 4
- What it carries 5
- The waveform 5
- Network design and capacity 5
- Listening to it 5

HFDL ground stations and frequencies 5
Aviation voice-side signalling: SELCAL 7
Maritime distress: HF DSC after GMDSS modernisation 8
- The US Coast Guard's HF posture 8
- What changed on 1 January 2024 9

Maritime safety broadcasts: weatherfax, RTTY and SITOR-B 10
- Radiofacsimile (HF weatherfax) 10
- Weather RTTY: Deutscher Wetterdienst, Pinneberg 10
- SITOR-B and HF NAVTEX 10

Maritime email: PACTOR and SailMail 11
- The protocol 11
- Who runs the networks 11

NATO narrowband workhorses: STANAG 4285 and the 110/4539 serial tone 12
- STANAG 4285: the broadcast modem 12
- MIL-STD-188-110 / STANAG 4539 and the ARQ layer 13
- Chat over HF: XMPP on STANAG 5066 14

Automatic Link Establishment: 2G still dominates, 4G arriving 14
- 2G ALE (MIL-STD-188-141A/B Appendix A) 14
- 3G ALE (STANAG 4538) 14
- 4G ALE / WALE (MIL-STD-188-141D Appendices G and H) 14

Wideband HF: STANAG 5069 and MIL-STD-188-110D 15
Tactical data links: Link 11 and Link 22 16
- Link 11 (MIL-STD-6011 / STANAG 5511) 17
- Link 22 (NILE, STANAG 5522) 17

Russian, Chinese and other non-NATO military signals 18
Russian modems: CIS-12 and relatives 18
Over-the-horizon radar 18
Chinese data modes 18
Money on the ionosphere: HF links for high-frequency trading 19
Evidence that it is happening 19
The fight over rules: RM-11953 19
Digital broadcasting: DRM on shortwave 20
Bottom line 21
Sources 22

How to measure 'popular' when there is no PSKReporter

The earlier amateur-band report could rank modes by spot counts, because FT8, RTTY and PSK31 stations report each other to public networks. Nothing like that exists for professional HF traffic. Military operators do not publish logs, much of the traffic is encrypted, and coast stations and aeronautical networks run under their own frequency allocations, well away from the amateur bands. "Popular" therefore has to be pieced together from four kinds of evidence:

- **Aggregated reception data where it exists.** Aviation's HFDL is the one professional mode with a public, crowd-sourced picture. Hobbyist receivers running the open-source dumphfdl decoder feed Airframes and hfdl.observer, which show which ground stations and frequencies are active at any moment [4].
- **Regulatory carriage requirements.** For ships, what is mandatory tells you what is on the air. HF DSC is watched by coast guards, while HF narrow-band direct printing (NBDP) was dropped from the GMDSS on 1 January 2024 [8] [9].
- **Monitoring-community status flags.** The Signal Identification Wiki (sigidwiki) marks each signal active, inactive or intermittent, and points to the Utility DXers Forum logs for month-by-month usage of modes such as STANAG 4285 [1] [21].
- **Vendor and standards documents.** These say which waveforms are still "in use" and which are "rare". RapidM's waveform table is an example [2].

The resulting ranking is qualitative and you should read it that way. None of the sources gives a share figure comparable to FT8's share of amateur spots, and this report does not invent one.

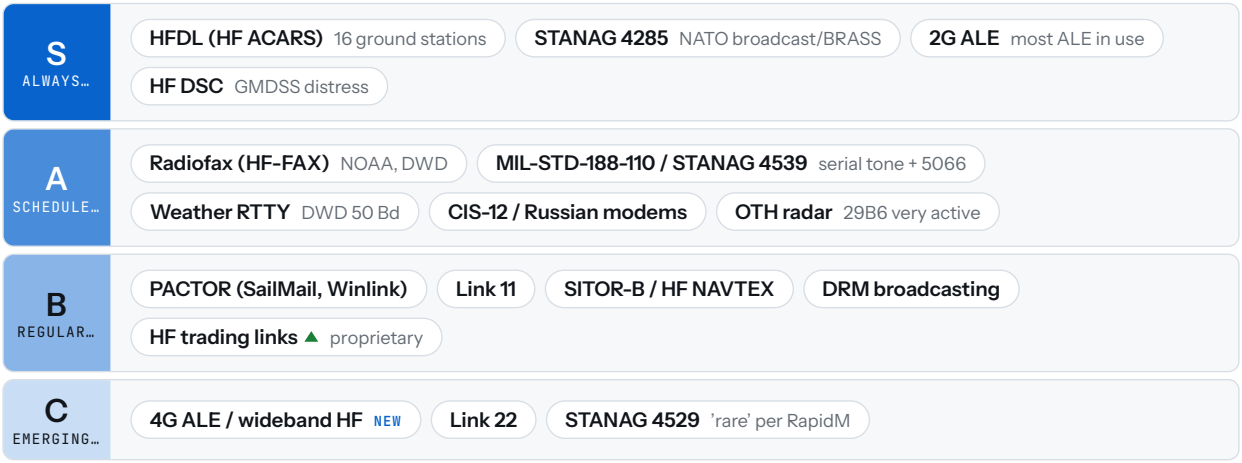
16	5	240 kbps	1 Jan 2024	45
HFDL ground stations in the current dumphfdl system table (v52)	HF DSC distress frequencies the US Coast Guard watches	Top rate of wideband HF (STANAG 5069, 48 kHz)	NBDP removed from GMDSS carriage rules	DRM shortwave entries on the B26 schedule

The short list: what you will actually hear

If you tune 2–30 MHz with an SDR and a wire antenna, most of the non-amateur digital signals you meet will come from a fairly small group of modes. The tiers below are this desk's judgement.

They rest on how reliably each mode can be found, how many users carry it, and whether the sources describe it as current. They are not traffic measurements.

Most-heard non-amateur HF digital modes, late 2026



Desk judgement from sigidwiki active flags, RapidM 'in use/rare' status, USCG and IMO carriage rules and HFDL aggregator data, as of November 2026.

Why the tiers fall this way

The S tier is made up of systems that run around the clock on published frequencies. Each HFDL ground station keeps several channels active at all times and moves them as propagation changes [4]. Ships' HF DSC watch is mandatory, so coast stations transmit acknowledgements and test calls every day [8]. STANAG 4285 is the waveform behind NATO's ship-shore broadcast systems, and RapidM's table lists it as "in use" for "NATO BRASS Systems, B/Cast Systems" [2]. Broadcast transmitters often key up continuously, which is why 4285 is so easy to find. Sigidwiki says the "vast majority" of ALE systems in use are still second generation, and their short sounding bursts turn up across the HF spectrum [15].

The A tier is scheduled or ubiquitous traffic. Radiofax and weather RTTY follow published timetables [10] [11]. The MIL-STD-188-110 serial tone is the default data modem under STANAG 5066 [2]. Russian modem networks and over-the-horizon radars are wideband or long-running enough that any monitor in Europe will see them [21].

The B tier covers real but more specialised traffic. PACTOR depends on ships connecting to coast stations [13]. Link 11 appears only when navies are exercising [18]. DRM's schedule is concentrated on a handful of broadcasters [27]. HF trading links are proprietary and have been growing since 2020 [23].

Quick reference

MODE	USER	MODULATION	BANDWIDTH	TYPICAL RATE	DECODABLE IN THE CLEAR?
HFDL (ARINC 635/753)	Airlines, ATC data link	BPSK/QPSK	2.4 kHz	300–1200 bps	Yes
SELCAL	Aviation (alerts before voice)	Four audio tones	~3 kHz voice channel	n/a	Yes

MODE	USER	MODULATION	BANDWIDTH	TYPICAL RATE	DECODABLE IN THE CLEAR?
HF DSC	Ships, coast guards	FSK	narrow	100 Bd	Yes
Radiofax	Weather services	FM-on-SSB (F3C)	~3 kHz	120 rpm / IOC 576	Yes (images)
Weather RTTY	DWD Pinneberg	FSK (F1B)	±225 Hz shift	50 Bd	Yes
SITOR-B / NAVTEX	Maritime safety information	FSK	170 Hz shift	100 Bd	Yes
PACTOR I–IV	Ship email, Winlink	FSK → PSK/QAM	up to ~2.4 kHz	20–5200 bps net	Partly (PMON)
STANAG 4285	NATO broadcast, BRASS	PSK	2.75 kHz	75–3600 bps	Modem yes; payload often encrypted
MIL-STD-188-110 / STANAG 4539	US/NATO data	PSK/QAM	3 kHz	75–9600 bps	Modem yes; payload often encrypted
2G ALE	Military, government, NGOs	8-FSK	2 kHz	125 Bd	Yes (addresses)
4G ALE + STANAG 5069	Military wideband	8PSK; PSK/QAM	3–48 kHz	to 240 kbps	Rarely
Link 11	Navies	multitone PSK	~3 kHz	1364 / 2250 bps	No (encrypted)
CIS-12 (MS5)	Russian military	12-tone PSK	3.1 kHz	to 4800 bps	Modem yes; content scrambled
DRM30	Broadcasters	OFDM	10 kHz typical	audio	Yes

The figures come from the sections that follow, each with its own citation. “Decodable” means public hobby or professional software can demodulate the signal. It does not mean the content is readable: most military payloads are encrypted, and sigidwiki says this plainly about CIS-12[20].

Aviation: HFDL, the busiest civilian data mode

High Frequency Data Link (HFDL) is the closest thing professional HF has to FT8: always on, worldwide, and easy to decode with free software. It goes by several names: **HF-ACARS, ARINC 753, ARINC 635 and HF DATALINK**[3]. Aircraft use it to send short messages over long distances where VHF data link and radar coverage end, mainly over the oceans, the polar routes and remote continental areas[4].

What it carries

HFDL is a carrier for ACARS. Its traffic includes airline operational messages (AOC), **ADS-C position reports** and **CPDLC** controller-pilot messages [4] [6]. That mix is what makes it useful to listeners. Airframes notes that position reports received over HFDL "can show aircraft crossing the Atlantic, Pacific, and polar routes in near real-time" [4]. For oceanic air traffic control the same reports replace radar: an aircraft over the mid-Atlantic with no satellite data link reports its position automatically by HF.

The waveform

Sigidwiki lists HFDL as **PSK in a 2.4 kHz channel on USB, from 2.9 to 22 MHz**. Its reference samples are **300 bps short (BPSK), 600 bps long (BPSK) and 1200 bps short (QPSK)** [3]. On the aircraft side all that is needed is a Communications Management Unit and an HFDL data radio. The CMU is the onboard router that also connects SATCOM, VHF data link and the flight management system [6]. Because the mode is digital, Wikipedia's summary says it uses **between one-third and one-half of the bandwidth that voice needs**, so data can still be decoded when voice is unusable. The example given is the **2003 Halloween solar storm**, when aircraft on polar routes kept using HFDL while HF voice was unusable [6].

Network design and capacity

Wikipedia describes "around 15" ground stations providing near-global coverage including both poles. Each station is designed for **4 channels**. At the time that text was written, 12 stations used half that capacity and 3 used three of the four channels [6]. The article carries a November 2025 warning that its "current" figures may be out of date. The dumphfdl system table described in the next section is a better guide to the present network. Aircraft and ground stations negotiate frequencies according to propagation, time of day and distance, and the active channels rotate through the day [4].

Listening to it

Airframes' recipe is short: an HF wire antenna at least **10 m long**, any HF-capable SDR (an RTL-SDR Blog V4 is enough), the **dumphfdl** decoder, and HFDLObserver to keep the frequency list current as propagation shifts [4]. One SDR can watch several frequencies of a single ground station at once. Older Windows tools such as PC-HFDL and MultiPSK, and professional decoders from Wavecom, Hoka and go2DECODE, also handle the mode [3].

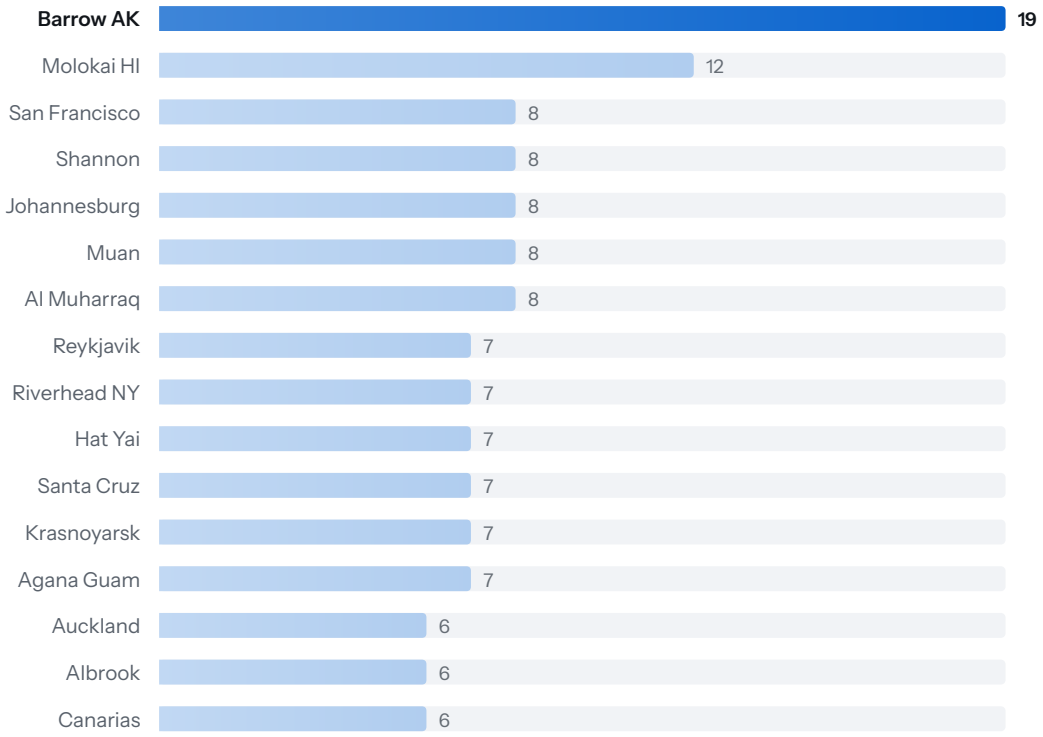
> KEY FINDING
>
> HFDL is the one professional HF data mode with a public aggregate picture (hfdl.observer, Airframes). If you want evidence that a band is open to a given region, HFDL squitters from a known ground station are a reliable propagation beacon.

HFDL ground stations and frequencies

The best current list of the network is the system table that ships with dumphfdl. It is the same data the ground stations broadcast to aircraft. The copy read for this report is **version 52** and lists

16 stations with IDs 1–17. ID 12 is absent [5]. Airframes publishes the same 16 locations [4]. Barrow, Alaska has by far the longest frequency list, with **19 assigned frequencies**, which fits its job of covering the Arctic and North Pacific routes in both daytime and night-time propagation. The lowest assignment in the table is **2941 kHz** (Muan) and the highest is **21997 kHz** (Santa Cruz) [5].

Assigned HFDL frequencies per ground station (system table v52)



Source: dumphfdl etc/systable.conf, version 52.

Assigned frequencies are not all on air at once. A station keys a subset suited to the moment's propagation, and hfdl.observer shows which of them are active in real time [4]. For a first attempt in Europe, the Shannon and Reykjavik lists are the obvious starting points. In North America, start with Riverhead and San Francisco. Several frequencies are shared between stations: **17919 kHz** appears in the San Francisco, Molokai, Riverhead, Barrow and Guam lists, and **13276 kHz** in San Francisco, Molokai and Riverhead [5]. One receiver parked on such a frequency can therefore hear more than one ground station.

Full HFDL frequency list by station (kHz, system table v52)

- 1 San Francisco, California — 21934, 17919, 13276, 11327, 10081, 8927, 6559, 5508
- 2 Molokai, Hawaii — 21937, 17919, 13324, 13312, 13276, 11348, 11312, 10027, 8936, 8912, 6565, 5514
- 3 Reykjavik, Iceland — 17985, 15025, 11184, 8977, 6712, 5720, 3900
- 4 Riverhead, New York — 21931, 17919, 13276, 11387, 8912, 6661, 5652

- 5 Auckland, New Zealand — 17916, 13351, 10084, 8921, 6535, 5583
- 6 Hat Yai, Thailand — 21949, 17928, 13270, 10066, 8825, 6535, 5655
- 7 Shannon, Ireland — 11384, 10081, 8942, 8843, 6532, 5547, 3455, 2998
- 8 Johannesburg, South Africa — 21949, 17922, 13321, 11321, 8834, 5529, 4681, 3016
- 9 Barrow, Alaska — 21937, 21928, 17934, 17919, 11354, 10093, 10027, 8936, 8927, 6646, 5544, 5538, 5529, 4687, 4654, 3497, 3007, 2992, 2944
- 10 Muan, South Korea — 21931, 17958, 13342, 10060, 8939, 6619, 5502, 2941
- 11 Albrook, Panama — 17901, 13264, 10063, 8894, 6589, 5589
- 13 Santa Cruz, Bolivia — 21997, 17916, 13315, 11318, 8957, 6628, 4660
- 14 Krasnoyarsk, Russia — 21990, 17912, 13321, 10087, 8886, 6596, 5622
- 15 Al Muharraq, Bahrain — 21982, 17967, 13312, 10030, 8885, 6646, 5544, 2986
- 16 Agana, Guam — 21928, 17919, 13312, 11306, 8927, 6652, 5451
- 17 Canarias, Spain — 21955, 17928, 13303, 11348, 8948, 6529

The table changes. Stations are added, dropped and re-frequencied, and the version number goes up each time, so check the live file before you build a monitoring setup around a particular frequency[3][5].

Aviation voice-side signalling: SELCAL

SELCAL is not a data mode, but it is the most common digital-style signalling on the aeronautical HF voice frequencies, and listeners hear it constantly between oceanic position reports. Crews keep the HF volume low because of the noise. A ground operator who wants a particular aircraft keys its **four-letter SELCAL code**, and the encoder converts it into **two pairs of simultaneous audio tones**. Each pair lasts **about one second**, with **roughly 0.2 seconds** of silence between them[7]. Only the aircraft whose decoder matches the code sounds a chime or lights a lamp. The crew then turns the volume up and confirms by voice that the call was for them. The current specification is **ARINC Characteristic 714A**[7].

Each letter stands for a fixed audio frequency. The low end of the table is **A = 312.6 Hz, B = 346.7 Hz, C = 384.6 Hz, D = 426.6 Hz, E = 473.2 Hz, F = 524.8 Hz, G = 582.1 Hz**[7]. Because the tones are spaced so that harmonics do not collide, an ordinary audio tone decoder can identify the code. Hobby logs therefore often match HF voice traffic to individual airframes by SELCAL.

SELCAL and HFDL are the two halves of oceanic HF operations. The versus block below sets them side by side using the figures cited above.

	HFDL (data)	VS	HF voice + SELCAL
What it carries	ACARS, ADS-C positions, CPDLC clearances	·	Spoken position reports and clearances
Signal	PSK bursts, 300–1200 bps	·	SSB voice preceded by four-tone call
Channel width	2.4 kHz	·	Standard ~3 kHz voice channel
Crew workload	Automatic	·	Crew alerted by chime, then voice
Behaviour in poor propagation	Still decodable when voice fails (2003 storm)	·	Degrades first
Standard	ARINC 635 / 753	·	ARINC 714A

Sources: sigidwiki HFDL; Wikipedia HFDL and SELCAL articles.

In practice an airliner crossing the North Atlantic without satellite data link uses both. HFDL sends its ADS-C reports automatically. Voice and SELCAL remain the fallback and are used for anything that needs a conversation.

Maritime distress: HF DSC after GMDSS modernisation

For ships, the HF digital signal that matters most legally is **Digital Selective Calling (DSC)**. It is the automated alerting and calling system of the GMDSS. A DSC-equipped HF marine radio sends a distress alert when the red button is pressed, and it also handles routine calls and test calls. Over the past few years DSC has become the *only* HF distress channel the US Coast Guard watches.

The US Coast Guard's HF posture

Effective **7 February 2022**, the US Coast Guard stopped watchkeeping on all HF voice distress frequencies in the contiguous United States and Hawaii. The one exception is **Kodiak, Alaska and Guam on 4125 kHz**. Voice watch on 6215 and 8291 kHz at those two sites was also discontinued, which went further than the original bulletin MSIB 10–21 announced [8]. Watch now continues on HF DSC on five assigned frequencies:

DSC FREQUENCY (ASSIGNED)	NOTE
4207.5 kHz	Test calls auto-acknowledged by all listed stations except Sector Guam
6312 kHz	Distress and calling
8414.5 kHz	Distress and calling
12577 kHz	Distress and calling
16804.5 kHz	Distress and calling

The Coast Guard notes that these are *assigned* frequencies and that the **carrier is 1700 Hz below** them. Anyone setting up an SDR decoder needs to make that offset[8]. The watching stations are Portsmouth/NMN, Boston/NMF, Miami/NMA, New Orleans/NMG, Point Reyes/NMC, Honolulu/NMO and Kodiak/NOJ. Each has its own MMSI, and the universal US Coast Guard shore identity is **003669999**[8]. The page also lists the amateur Maritime Mobile Service Network on 14,300 kHz as a supplementary resource, and Inmarsat-C or Iridium LT-3100S terminals as the satellite alternative[8].

For listeners, HF DSC traffic is mostly automated. Coast stations acknowledge test calls, ships make routine calls, and genuine distress relays are occasional. Every message carries MMSIs, and many carry positions.

What changed on 1 January 2024

The modernised GMDSS took effect on **1 January 2024** through amendments to SOLAS Chapter IV[9]. Three changes matter for HF:

- **NBDP is no longer part of GMDSS.** It was removed from all GMDSS equipment requirements. The option of meeting sea-area A3 obligations with MF/HF radio-telex is gone, and from that date A3 ships must carry a Recognized Mobile Satellite Service ship earth station. In early 2024 that meant Inmarsat-C or the Iridium LT-3100S[9].
- **Satellite is no longer a monopoly.** Iridium was recognised by the IMO in 2020. With Iridium, sea area A3 becomes global and A4 effectively disappears for that ship[9].
- **Rules are written generically.** References to Inmarsat, NAVTEX and EGC were replaced with general terms such as “recognized mobile satellite service”[9].

HF DSC and HF voice remain part of the system. The traffic that has been squeezed out is HF telex. This explains why SITOR/NBDP traffic, once among the most common maritime utility signals, now sits in the B tier.

1 Aug 1993 — **NAVTEX carriage mandated**
SOLAS requires certain vessel classes to carry NAVTEX receivers

2020 — **Iridium recognised for GMDSS**
Ends Inmarsat’s monopoly as satellite GMDSS provider

7 Feb 2022 — **USCG ends HF voice distress watch**
Except Kodiak and Guam on 4125 kHz; HF DSC watch continues

1 Jan 2024 — **Modernised GMDSS in force**
NBDP removed from GMDSS; A3 redefined around recognised satellite services

Nov 2025 — **USCG HF DSC page reconfirmed**
Five DSC frequencies and station MMSIs listed as effective

1 Jan 2028 — **VHF channelling rules (postponed)**
Four-digit VHF channel display requirement deferred from 2024

Maritime safety broadcasts: weatherfax, RTTY and SITOR-B

Some of the steadiest professional signals on HF are one-way broadcasts from coast guards and weather services. They follow fixed timetables, transmit in the clear, and can be decoded with free software. That makes them the easiest professional signals to start with.

Radiofacsimile (HF weatherfax)

The US example is **NMF Boston**, keyed by the Coast Guard for NOAA's Ocean Prediction Center. Its published schedule lists four frequencies, all **F3C emission at 4 kW** [10]:

FREQUENCY	HOURS (UTC)
4235 kHz	0230–1039
6340.5 kHz	All broadcast times
9110 kHz	All broadcast times
12750 kHz	1400–2239

Every chart goes out at **120 rpm with an index of cooperation of 576**. The products include preliminary and full surface analyses split into north-east and north-west Atlantic halves, 500 mb analyses, wind/wave analyses and forecasts from 24 to 96 hours, satellite images, sea-state analysis and ice charts. From 1 December to 14 May the tropical cyclone danger chart is replaced by a 48-hour high wind/wave warning chart [10]. The schedule's note says the **carrier frequency is 1.9 kHz below the assigned frequency**. In USB, tune 1.9 kHz lower so the fax tones fall in the passband [10]. Treat the document's dates with care: it says "schedule effective Sep 04, 2018, information dated March 16, 2023". The timetable is long-standing, and this desk has not confirmed it against a 2026 update [10].

Weather RTTY: Deutscher Wetterdienst, Pinneberg

Germany's weather service is one of the last large users of classic radioteletype for shipping. Its RTTY schedule from Pinneberg lists **4583 kHz (DDK2, 1 kW), 7646 kHz (DDH7, 1 kW) and 10100.8 kHz (DDK9, 10 kW)**. All three use **F1B at 50 baud with ±225 Hz shift**, which is the 450 Hz shift that decoders such as fldigi expect for this service [11]. The programme carries storm warnings for the German Bight and the western and southern Baltic, sea-weather reports for the North Sea and Baltic, coded SYNOP observations from coastal stations in Europe, North America and North Africa, and ship reports from the North Atlantic [11]. The schedule read for this report is the September 2023 edition. DWD also publishes a separate fax schedule.

SITOR-B and HF NAVTEX

NAVTEX itself is a medium-frequency service on **518 kHz** (international, English) and **490 kHz** (national languages). National maritime safety information is also sent on HF at **4209.5 kHz** in FEC mode [12]. The format is SITOR collective B-mode: **binary FSK at 100 baud with 170 Hz shift**, the CCIR 476 seven-bit character set, and forward error correction by repeating each character after a three-character delay. Each message opens with a phasing signal of at least ten seconds and

the four characters “ZCZC”[12]. Because NBDP is no longer a GMDSS carriage requirement[9], HF SITOR is declining. Monitors still hear it from coast stations that keep broadcasting safety information and weather bulletins in that format.

> CAUTION
>
> The schedules cited here (NOAA 2018/2023, DWD 2023) are the latest published documents this desk could read. Broadcast lists change with little notice, so check the issuing agency before relying on a specific frequency or time.

Maritime email: PACTOR and SailMail

Before cheap satellite terminals arrived, the usual way for a yacht or small commercial vessel to send email from mid-ocean was a marine SSB radio connected to a PACTOR modem. That traffic is still on the air in the maritime mobile bands, although it now competes with satellite.

The protocol

PACTOR was developed by **Special Communications Systems GmbH (SCS)** and released in **1991**. It combined the bandwidth efficiency of packet radio with the CRC error checking and ARQ of AMTOR[13]. Users are listed as marine radio stations, amateurs, isolated stations, and government users including the **US Department of Homeland Security and its cybersecurity agency CISA**, through the SHARES HF programme[13]. It is half-duplex on a single frequency, with stations alternating in **1.25–1.4 second cycles**. That produces the familiar “chirp–pause–chirp” rhythm on a waterfall[13]. Depending on the generation and conditions, net throughput runs from **20 to 5200 bit/s**, or **9000 bit/s gross at speed level 10 (32-QAM)**[13]. ITU emission designators grow from **340HJ2D/440HJ2D for PACTOR I** to **2K20J2D or 2K40J2D for PACTOR IV**, which runs at up to 1800 symbols per second[13].

Only PACTOR I is open source. Levels II–IV are proprietary but publicly documented, and third parties can monitor them with the free **PMON** software for Raspberry Pi or the PMON utility built into SCS modems[13]. That is the “partly” in the quick-reference table: you can read unencrypted traffic, but the protocol is not open in the way FT8 is.

Who runs the networks

SailMail is a non-profit association of yacht owners. It runs its own **worldwide network of SSB-PACTOR private coast stations in the Maritime Mobile Radio Service**, free to members who have an SSB radio and a PACTOR modem[14]. SailMail’s email system also runs over Iridium, Inmarsat, VSAT, Globalstar, Thuraya, Wi-Fi and cellular networks. The association says plainly that many members use the HF network “to avoid data charges” but carry Iridium or another satellite service “as a backup and for urgent communications in times of difficult HF propagation”[14]. That sentence sums up maritime HF data in 2026: valued because it costs nothing per message, no longer the only option.

On the amateur and emergency side, **Winlink**, run under the Florida-based non-profit ARSFI, runs a volunteer network of PACTOR gateways that connect radio to the internet. Wikipedia describes

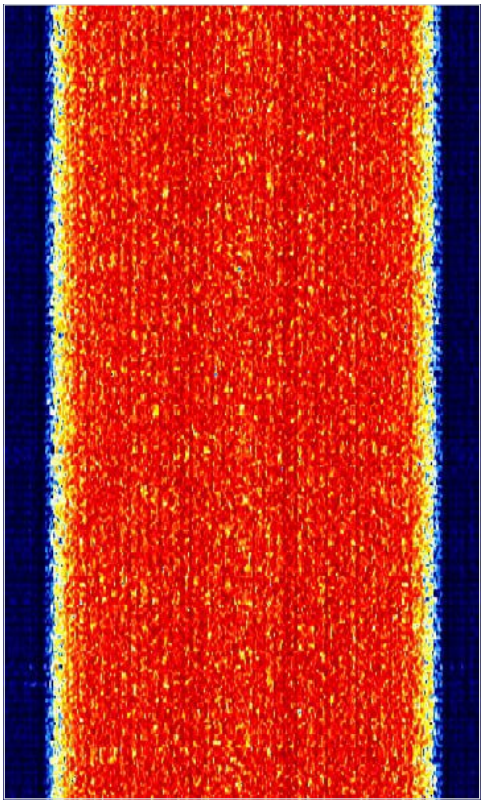
it as extending internet access “to sea-based and other isolated users”[13]. Winlink traffic largely sits in the amateur bands, which is why it appeared in the earlier amateur report. SailMail’s coast stations are the commercial-maritime counterpart.

KEY FINDING

PACTOR is a mode in decline but not dead. Satellite has taken the urgent and high-volume traffic, while HF PACTOR survives where cost per message matters and as a backup independent of any satellite operator.

NATO narrowband workhorses: STANAG 4285 and the 110/4539 serial tone

Western military data traffic on HF is carried by a family of single-carrier PSK modems. They look alike on a waterfall: a featureless, flat-topped block about 3 kHz wide. They differ in framing, rates and where they are used.



STANAG 4285 on a waterfall: a featureless single-carrier block about 2.75 kHz wide, which is how most NATO serial-tone traffic looks. Image: sigidwiki.com

STANAG 4285: the broadcast modem

STANAG 4285 is defined in NATO’s “Characteristics of 1200/2400/3600 Bits per Second Single Tone Modulators/Demodulators for HF Radio Links”. Sigidwiki describes it as “very similar” to the MIL-STD-188-110 serial tone[1]. It always runs at **2400 baud**. The user rate is changed by switching modulation and FEC:

USER RATE	MODULATION	FEC RATE	INTERLEAVING
3600 bps	8PSK	none	none
2400 bps	8PSK	2/3	short or long
1200 bps	QPSK	1/2	short or long
600 bps	BPSK	1/2	short or long
300 bps	BPSK	1/4	short or long
150 bps	BPSK	1/8	short or long
75 bps	BPSK	1/16	short or long

Short interleaving gets messages through faster but copes less well with fading. Long interleaving takes longer and is more robust[1]. RapidM explains why the mode is so easy to find. The older STANAG waveforms “find use in shore to ship and strategic broadcast systems” and are “well suited to broadcast because of the built-in continuous synchronisation sequences”. RapidM lists 4285 as **in use for “NATO BRASS Systems, B/Cast Systems”** [2]. A naval broadcast transmitter keys continuously whether or not it has traffic, so a 4285 signal stays on a frequency for hours. That is why it is one of the most commonly logged military signals in Europe. The payload is almost always encrypted: you can demodulate the modem, but you will not read the messages.

MIL-STD-188-110 / STANAG 4539 and the ARQ layer

The serial-tone modem of **MIL-STD-188-110B/D** and **STANAG 4539** is, in RapidM’s words, “the same waveform”, often called “110B”[2]. It is the standard choice for point-to-point data rather than broadcast. Rates run **75–9600 bps in 3 kHz**, and Appendix F’s independent-sideband version reaches **19,200 bps in 6 kHz** [2]. RapidM says it is “normally associated with the STANAG 5066 ARQ protocol”. Its **autobaud** capability lets STANAG 5066 change data rate quickly as the ionosphere changes, and it is “often coupled with 2nd or 3rd Generation ALE”[2]. All of these narrowband PSK waveforms except STANAG 4529 use **one carrier centred at 1800 Hz at 2400 symbols per second**, with rate-1/2, K=7 convolutional coding[2].

STATUS (RAPIDM)	WAVEFORM	MAX RATE	BANDWIDTH	USE
in use	STANAG 4481 (FSK)	75 bps	120 Hz	NATO ship-to-ship minimum requirement
in use	STANAG 4415 (NATO robust)	75 bps	3000 Hz	Robust low-rate mode
in use	MIL-STD-188-110A	2400 bps	3000 Hz	Legacy serial tone
in use	STANAG 4539 / 110B	9600 bps	3000 Hz	ARQ with fast data-rate change
in use	110B Appendix F	19200 bps	6000 Hz	Two-ISB ARQ
in use	STANAG 4285	2400 bps	3000 Hz	BRASS, broadcast
in use	STANAG 4481 PSK	300 bps	3000 Hz	Ship-to-ship
rare	STANAG 4529	1200 bps	1500 Hz	Broadcast, “2 per 3 kHz channel”

The 4285 row above gives RapidM's 2400 bps maximum, which is the coded rate. Sigidwiki's 3600 bps is the uncoded mode [1] [2].

Chat over HF: XMPP on STANAG 5066

A newer use of this stack is visible on the air. Sigidwiki documents military **XMPP multi-user chat** sent over STANAG 5066, using the 110A serial waveform at a fixed **600 bps**. It has been logged on frequencies between **2082.5 and 7807.2 kHz**, including 3112.2, 4022.2 and 5742.2 kHz [19]. The page describes XMPP as "widely used for military deployments, where operation over constrained and degraded networks is often essential" [19]. In practice, group chat is replacing teletype-style message handling in tactical HF networks.

Automatic Link Establishment: 2G still dominates, 4G arriving

ALE lets HF radio work more like a telephone. Every station in a network keeps scanning a list of channels. When an operator "dials" an address, the controller picks the best idle channel for that destination, checks that it is clear, and sends a short selective call. The called station stops scanning, the two controllers handshake to confirm the link is good enough, and only then are the operators told the circuit is up [15]. Idle stations also send periodic **soundings**, so every radio builds a running picture of which frequencies reach which partners. Those soundings are why ALE bursts appear across the HF spectrum, day and night, wherever military, government or NGO networks operate.

2G ALE (MIL-STD-188-141A/B Appendix A)

Second-generation ALE uses **8-tone MFSK at 125 baud with 250 Hz tone spacing**, which gives a **2 kHz** wide signal in USB. Sigidwiki has logged it from **3.068 to 28.3125 MHz** [15]. The wiki says the vast majority of ALE systems in use "at the present time are 2G ALE" [15]. That matches what monitors see. 2G is in US and allied military networks, the USAF HF Global Communications System, government agencies, embassies and humanitarian organisations, and amateur ALE nets. A hobby decoder shows the station addresses in plain ASCII, which is why ALE logs are the main way monitors identify networks. Hobby decoders include MultiPSK (which labels it "141A"), Black Cat ALE, PC-ALE and Sorcerer; professional tools include go2DECODE and Hoka [15].

3G ALE (STANAG 4538)

Third generation adds burst PSK waveforms, synchronous scanning and faster link set-up (FLSU). It shares the 1800 Hz, 2400-symbol serial-tone core [16]. 3G has been fielded, but the sources describe it as a minority alongside 2G rather than its replacement.

4G ALE / WALE (MIL-STD-188-141D Appendices G and H)

Fourth-generation ALE is built for wideband HF. The handshake still runs in a normal **3 kHz** channel, using one of two 8PSK burst waveforms at 2400 symbols per second on an 1800 Hz subcarrier [16]:

- **Deep WALE**: a 240 ms Walsh-coded preamble and about **1.28 s per PDU**. Very robust, but slow.

- **Fast WALE**: a 120 ms preamble and about **120 ms per PDU**.

During the handshake each side reports the spectrum it can use as **16-element sub-channel vectors** of 1.5 or 3 kHz each. The traffic channel, **up to 48 kHz**, is computed independently for each direction, so a link can route around local interference [16]. 4G stations can still place and accept 2G calls and 3G FLSU calls. With linking protection enabled, PDUs are encrypted with **HALFLOOP-96** [16].

	2G ALE	vs	4G ALE (WALE)
Standard	MIL-STD-188-141A/B App. A	·	MIL-STD-188-141D App. G/H
Modulation	8-tone MFSK, 125 Bd	·	8PSK burst, 2400 Bd, 1800 Hz subcarrier
Handshake bandwidth	2 kHz	·	3 kHz
Traffic channel	Separate 3 kHz modem	·	Negotiated, up to 48 kHz
Addresses on air	Plain ASCII, readable	·	16-bit binary, optionally HALFLOOP-encrypted
Prevalence	'Vast majority' of ALE in use	·	Emerging

Sources: sigidwiki 2G and 4G ALE pages.

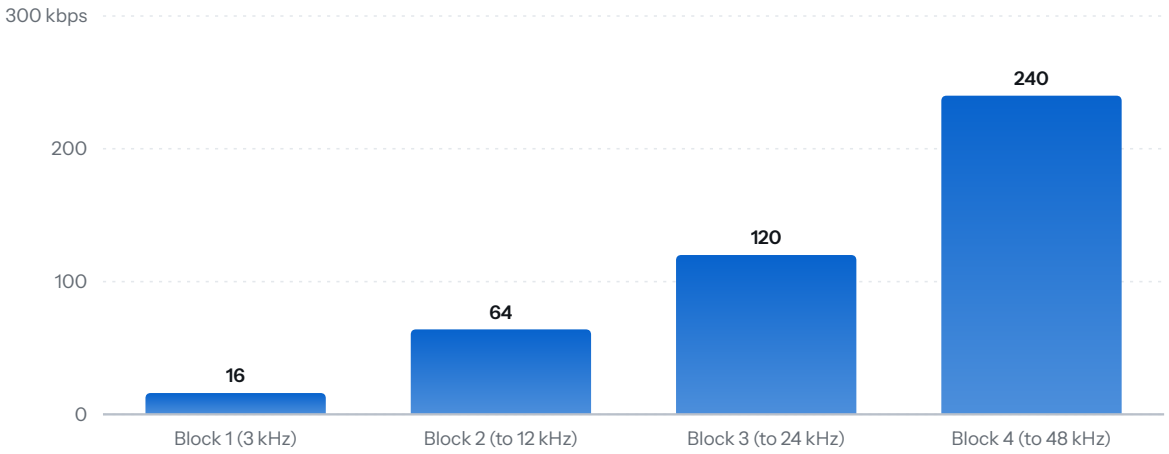
For a listener, the practical result is that 2G ALE will stay the most readable military signal on HF for years. As networks move to 4G with linking protection, the plain-text addresses that make ALE logging possible will disappear.

Wideband HF: STANAG 5069 and MIL-STD-188-110D

The largest technical change in military HF over the past decade has been the move past the 3 kHz voice channel. **MIL-STD-188-110D Appendix D** and its NATO counterpart **STANAG 5069** define wideband HF (WBHF) serial-tone waveforms in channels from **3 kHz to 48 kHz**, in 3 kHz steps up to 24 kHz and then 30, 36, 42 and 48 kHz [2] [17]. Within each bandwidth a **waveform ID (WID) from 0 to 13** selects the modulation. The range runs from Walsh-coded and BPSK modes, through QPSK and 8PSK, up to 16-, 32-, 64- and 256-QAM [2]. Rates run from **75 bps** at WID 0 in 3 kHz to **240,000 bps** at WID 12 (256-QAM) in 48 kHz [2].

Equipment is sold in four capability blocks:

Maximum data rate by WBHF capability block (MIL-STD-188-110D App. D / STANAG 5069)



Source: RapidM waveform tables.

According to RapidM, Block 1 is 3 kHz only, “with somewhat improved performance over STANAG 4539 3-kHz modems”. Block 2 adds 6, 9 and 12 kHz with K=7 coding. Blocks 3 and 4 extend to 24 and 48 kHz and add K=9 coding[2]. The same table shows how sharply rates fall when conditions are poor. A 48 kHz channel still carries only **1200 bps** at WID 0, so the large figures depend on a very good channel[2].

WBHF and 4G ALE are designed as a pair. The WALE handshake measures and negotiates the contiguous spectrum, and the 110D Appendix D modem then uses it[16].

On the air, a wideband HF signal looks unlike anything else military: a flat block tens of kilohertz wide, often in the 2–8 MHz range where military fixed-service allocations are wide enough to hold it. The XMPP-over-5066 traffic described above has been logged with a **34 kHz** occupied bandwidth[19]. This desk could not find a public count of how widely WBHF has been fielded. Vendors such as RapidM sell modems with Block 3 as standard and Block 4 as an option[2], but deployment figures by service or nation are not public. For that reason it sits in the “emerging” tier here rather than among the most-heard modes.

KEY FINDING

Wideband HF is why the 3 kHz SSB channel is no longer the hard limit on military HF data rates. In good conditions a 48 kHz WBHF link carries about 25 times the throughput of a 9600 bps STANAG 4539 link.

Tactical data links: Link 11 and Link 22

Naval task forces share radar tracks with each other over tactical data links. On HF the older of these is Link 11, and its intended replacement is Link 22.

Link 11 (MIL-STD-6011 / STANAG 5511)

Link 11 dates back to the late 1950s, and its design history begins in **1957** [18]. It is a multitone, phase-modulated system. The HF version carries data at **2250 or 1364 bps**, using the conventional (CLEW) or single-tone (SLEW) waveform [18]. A Link 11 net is controlled by a Net Control Station that polls each participating unit in turn in a **roll call**. Each ship answers with its track data before control passes on. The result has a recognisable rhythm on a waterfall: a short net-control interrogation, then a longer burst from the polled unit, repeated round the net. Wikipedia mentions a Link 11 recording on **4469.3 kHz** in **2022** as an example of the system still in use [18]. Monitors in Europe and around the Mediterranean usually hear Link 11 during naval exercises rather than every day, which places it in the B tier. The content is encrypted.

RapidM's table still lists **STANAG 4539 Appendix F TDMA** as "in use" for "Link 11 & Link 22 waveforms", and describes STANAG 4539 TDMA as being "for use in older Link 22 systems" [2]. This desk could not establish a date for any NATO or US decision to retire Link 11 on HF.

Link 22 (NILE, STANAG 5522)

Link 22 came out of the **NATO Improved Link Eleven (NILE)** programme. Its stated purpose is to replace Link 11, "improve Allied interoperability", "complement Link 16" and "enhance the commanders' war fighting capability" [22]. It runs on HF and UHF. Between **2007 and 2009** Germany paid for work on Link 22's HF fixed-frequency (HF-FF) mode. That work made the standard data rates more robust, extended **gapless range to 1000 nautical miles** and added high-speed waveforms. Germany submitted the HF-FF technology to NATO in **2012**, and NILE approved it in **2015**, with full support expected in 2016 [22]. Every implementation runs one shared System Network Controller software package owned by the NILE nations. It is not sold commercially and goes to third-party nations for an annual maintenance fee [22].



Link 22 is harder to identify on HF than Link 11, and it is reported much less often in public monitoring logs. That fits a gradual transition in which navies still keep Link 11 for coalition interoperability.

Russian, Chinese and other non-NATO military signals

For a listener in Europe, a large share of the military HF activity that is not NATO comes from Russia. In the Pacific it comes from China. Most of it can be identified on a waterfall but not read: the modems are documented by the monitoring community, and the payloads are scrambled or encrypted.

Russian modems: CIS-12 and relatives

CIS-12, also catalogued as **MS5**, is associated with the Russian AT-3004D and AT-3104D modems. It is a parallel-tone PSK modem with **12 data tones at 120 baud**, reaching up to **4800 bps** in about a 3.1 kHz channel, with a pilot tone at about **3300 Hz** [20]. Sigidwiki states plainly that the content is scrambled, so decoding the modem does not yield readable text [20]. It belongs to a wider family of Russian parallel-tone and FSK modes catalogued by the wiki under its CIS entries. Since the full-scale invasion of Ukraine, Russian military HF has had particular attention from European monitors. This desk did not find a quantitative source on how its volume has changed, so none is claimed here.

Over-the-horizon radar

The loudest non-communications military signals on HF are over-the-horizon radars. Sigidwiki says Russia's **29B6 "Kontayner"** is "currently very active in Europe" [21]. Its features:

- Pulsed transmission with **frequency modulation on pulse (FMOP)**, where many other OTH radars use FMCW. It usually runs at **40 pulses per second**, which gives an unambiguous range of **3750 km**.
- Bandwidths of **3.5, 7, 14 or 28 kHz**, most often about 14 kHz, between **6.1 and 32 MHz**, sometimes on several beams and frequencies at once [21].
- About **150 antenna masts**. The receive site is near Kovylkino in Mordovia. The original transmit site at Gorodets was dismantled around 2018–2019 and a new transmitter built near Kovylkino. A facility in Kaliningrad has been planned [21].

The same wiki catalogues Chinese OTH radars ("OTH-SW" and "Foghorn"), Australia's JORN, the US ROTHR, PLUTO II on Cyprus, and civilian CODAR ocean radars [21]. Some are loud enough to wipe out amateur and utility signals over a wide stretch of spectrum, and they are among the most frequently reported "interference" on the amateur bands.

Chinese data modes

The most widespread Chinese digital mode in public logs is the **30-tone OFDM modem**, "believed to be used by Chinese military or other agencies". Each burst opens with a four-tone QPSK preamble spaced 600 Hz apart, followed by **30 BPSK-modulated OFDM tones** in about **3 kHz**, with a pilot near 445 Hz. It is usually sent in LSB [29]. Sigidwiki describes "a massive amount of transmissions" and lists **80 unique frequencies from 3618 to 18,656 kHz** [29]. Related Chinese entries on the wiki include the 4+4 diplomatic mode, PRC-16 (16×75) and a 64-tone MFSK mode [29].

CAUTION

Attributions in this section, such as “Chinese military” for the 30-tone modem, come from the monitoring community’s analysis rather than official confirmation. Treat them as well-founded identifications, not established fact.

Money on the ionosphere: HF links for high-frequency trading

The newest commercial user of HF is not shipping or aviation but finance. A skywave signal travels between continents at close to the speed of light in air. Light in optical fibre travels about a third slower, and fibre routes are not great circles. For a trader in Frankfurt reacting to a price move in Chicago, a few milliseconds of advantage is worth building transatlantic shortwave links for, even though they carry very little data.

Evidence that it is happening

The first public evidence came in **2018**. Bob Van Valzah, a performance engineer and radio amateur (KE9YQ), noticed a tower in **West Chicago, Illinois** carrying four large log-periodic HF antennas and a microwave dish. It was registered as a U.S. Cellular site, and in the trash pile inside the fence was a box from an **Ettus Research USRP X300** software-defined radio [24]. Using FCC database searches he found two more sites. The blog’s owner, who had covered microwave HFT networks since 2014, reported that “at least five HFT/market making firms” were behind shell companies building shortwave sites in the US, Germany and the UK, including one firm that had paid more than **$1 million** for a field [24].

Raft Technologies, a vendor in this market, says trading firms have been adopting HF links “since early 2020”. It cites Deutsche Börse analysis showing that HF across **CME (Chicago) to Eurex (Frankfurt)** had replaced traditional links for trading DAX futures on ES signals. A mid-2022 analysis by Deutsche Börse’s Stefan Schlamp found HF speeds giving about a **9 ms advantage** over the fastest transatlantic fibre-plus-microwave route [23]. In October 2024 the *Financial Times* reported on Skywave Networks and its claim that its “innovative and patented” technology addressed shortwave’s bandwidth problem [31].

The transmissions are proprietary. No public decoder or published waveform exists, and this desk found no reliable monitoring description of what the signals look like on air. They are known to exist from the paper trail, not from logs.

The fight over rules: RM-11953

In 2023 the **Shortwave Modernization Coalition (SMC)**, with Skywave Networks and FlexRadio among the parties named in the record, petitioned the FCC (**RM-11953**). It asked for new Part 90 rules allowing fixed, long-distance, non-voice communications **above 2 MHz and below 25 MHz** [25] [26]. ARRL’s opposition sets out what was proposed [26]:

RM-11953: SMC proposal vs existing Part 90 HF rules (per ARRL filing)

3 changes

ITEM	BEFORE	AFTER	CHANGE
Signal bandwidth	One voice channel (~3 kHz)	Up to 50 kHz	Change
Power limit at least +13 dB	1000 W PEP	20,000 W average	Change
Out-of-band emission mask ARRL says sidebands could intrude up to 100 kHz into ham bands	Current Part 90 limits	±250% of bandwidth, looser	Change

Source: ARRL Opposition to RM-11953, August 2023. Proposal only; not adopted as of this report.

ARRL argued that the rules “would cause widespread disruption to Amateur and other communications services on multiple spectrum bands”, noting that many of the Part 90 bands sit directly next to amateur allocations only 300–450 kHz wide [26]. Comments were due on **31 July 2023** and reply comments on **15 August 2023**, after the FCC refused Skywave’s and FlexRadio’s requests for more time [25] [26]. The ECFS filing history shows submissions continuing well after the comment cycle closed [30].

CAUTION

As far as this desk could establish, the FCC has not adopted rules or issued a notice of proposed rulemaking on RM-11953 as of November 2026. The FCC’s ECFS pages could not be read directly for this report, so check the docket before relying on that status.

Digital broadcasting: DRM on shortwave

Digital Radio Mondiale (DRM30) is the only digital mode used by international broadcasters on shortwave. On a waterfall it appears as a flat OFDM block, typically 10 kHz wide. It sits in the broadcast bands, so it is the easiest digital signal on HF to find with a cheap receiver running DREAM or a dedicated DRM set.

The DRM Consortium’s schedule for the **B26 season (25 October 2026 – 27 March 2027)** lists **45 broadcasts**. It was updated on **26 October 2026**, and some A26 entries are kept where B26 details are not yet confirmed [27]. The Consortium says the list is compiled from public sources and listener reports because “there is no single official directory of DRM broadcasts worldwide”, and that it is still provisional [28]. The same announcement marked the retirement of Jeff Cohen, who compiled the schedules for many years [28].

The schedule is dominated by one broadcaster:

BROADCASTER	EXAMPLE FREQUENCIES (KHZ)	SITE	POWER
China National Radio	13790, 17650, 17700, 11695, 9655	Qiqihar, Kunming, Beijing, Urumqi, Dongfang	30–150 kW
Radio Romania International	15250, 21470, 9580	Tiganesti	90 kW
BBC World Service	17575 (South Asia, 1500–1600 UTC)	Woofferton	100 kW
Music 4 Joy	13650 (Tue & Thu)	Nauen	100 kW
Europasender Waldheim	6195 (occasional)	Waldheim	0.2 kW ERP

Data from the B26 schedule [27]. The largest single CNR entry is **17700 kHz at 150 kW** from Beijing [27]. Most CNR transmissions are domestic Chinese-language services aimed within China, so outside Asia the more realistic targets are RRI and the BBC's DRM slot. The schedule's mix of "confirmed", "provisional" and "unverified" entries tells you how thin DRM's shortwave footprint still is outside China and India. It is a real, regularly scheduled digital service, but a niche one.

Bottom line

Outside the amateur bands, the HF digital spectrum in late 2026 is shaped by three groups of users:

- **Aviation's HFDL** is the busiest *readable* professional mode. Sixteen ground stations, published frequencies and free tools (dumphfdl, Airframes, hfdl.observer) make it the best first target. A 10 m wire and an RTL-SDR V4 are enough to start.
- **Maritime HF has narrowed to DSC, weatherfax, weather RTTY and email.** The US Coast Guard watches only HF DSC (4207.5, 6312, 8414.5, 12577 and 16804.5 kHz) and has stopped HF voice watch except on 4125 kHz at Kodiak and Guam. NBDP left the GMDSS on 1 January 2024. NOAA and DWD weatherfax and RTTY schedules are easy, decodable targets, but check the current schedules first.
- **Military traffic is the largest share and mostly unreadable.** STANAG 4285 broadcasts, 110B/4539 links running STANAG 5066, 2G ALE soundings, Link 11 during exercises, Russian CIS-12-family modems, Chinese 30-tone OFDM and OTH radars such as 29B6 fill much of the spectrum. You can identify these modes, but apart from ALE addresses you cannot read the content.

Two trends are worth watching. **Wideband HF with 4G ALE** will gradually remove both the 3 kHz signature and the readable addresses that monitoring depends on. **HF trading links** are a growing commercial use whose regulatory future depends on an FCC petition still open after three years. HF trading signals and Link 22 are the two areas where public evidence is thinnest, so treat any claim about their on-air volume with caution.

Terms used in this document (10)

- **ADS-C** — Automatic Dependent Surveillance – Contract — aircraft send position reports to air traffic control on an agreed schedule or when an event occurs.
- **ALE** — Automatic Link Establishment — a protocol that lets HF radios scan, sound and pick the best frequency automatically.
- **BRASS** — Broadcast and Ship-Shore — NATO's maritime HF communications architecture for fleet broadcasts and ship-to-shore traffic.
- **CPDLC** — Controller–Pilot Data Link Communications — text clearances and requests exchanged between air traffic control and the cockpit instead of voice.
- **GMDSS** — Global Maritime Distress and Safety System — the IMO framework that sets which radio equipment ships must carry and watch.
- **IOC** — Index of cooperation — a fax parameter that sets the image's aspect ratio; 576 is the standard for marine weather charts.
- **MMSI** — Maritime Mobile Service Identity — the nine-digit number that identifies a ship or coast station in DSC and AIS.
- **NBDP** — Narrow-band direct printing — maritime radio-telex (SITOR) used for safety messages and telex traffic.
- **STANAG** — NATO Standardization Agreement — the numbered NATO standards that define military modems and protocols.
- **WALE** — Wideband ALE — the fourth-generation link-establishment protocol that negotiates wideband HF channels.

SOURCES

1 STANAG 4285 – Signal Identification Wiki
https://www.sigidwiki.com/wiki/STANAG_4285

2 Narrowband and Wideband HF Waveforms – RapidM
https://www.rapidm.com/waveforms/

3 High Frequency Data Link (HFDL) – Signal Identification Wiki
https://www.sigidwiki.com/wiki/High_Frequency_Data_Link_(HFDL)

4 HFDL introduction – Airframes Documentation
https://docs.airframes.io/docs/technology/hfdl/intro/

5 dumphfdl systable.conf (HFDL system table v52)
https://github.com/szpajder/dumphfdl/blob/master/etc/systable.conf

6 High Frequency Data Link – Wikipedia
https://en.wikipedia.org/wiki/High_Frequency_Data_Link

7 SELCAL – Wikipedia
https://en.wikipedia.org/wiki/SELCAL

8 HF Distress and USCG Contact Frequencies – USCG Navigation Center
https://navcen.uscg.gov/hf-distress-uscg-contact-frequencies

9 The modernized GMDSS has entered into force – GMDSS Testers
https://gmdsstesters.com/radio-survey/general/the-modernized-gmdss-has-entered-into-force-how-will-radio-surveys-change-in-2024.html

10 NOAA/NWS HF radiofacsimile schedule, Boston NMF
https://tgftp.nws.noaa.gov/fax/hfmarsh.txt

11 DWD Pinneberg RTTY broadcast schedule (Sendeplan RTTY, 09/2023)
https://www.dwd.de/DE/fachnutzer/schifffahrt/funkausstrahlung/sendeplan_rtty_01_092023.pdf?__blob=publicationFile&v=1

12 NAVTEX – Wikipedia
https://en.wikipedia.org/wiki/NAVTEX

13 PACTOR – Wikipedia
https://en.wikipedia.org/wiki/PACTOR

14 SailMail
https://sailmail.com/

15 Automatic Link Establishment (2G ALE) – Signal Identification Wiki
https://www.sigidwiki.com/wiki/Automatic_Link_Establishment_(2G_ALE)

16 Automatic Link Establishment (4G ALE WALE) – Signal Identification Wiki
https://www.sigidwiki.com/wiki/Automatic_Link_Establishment_(4G_ALE_WALE)

17 STANAG 5069 – Signal Identification Wiki
https://www.sigidwiki.com/wiki/STANAG_5069

18 MIL-STD-6011 (Link 11) – Wikipedia
https://en.wikipedia.org/wiki/MIL-STD-6011

19 XMPP trials (STANAG 5066) – Signal Identification Wiki
https://www.sigidwiki.com/wiki/STANAG-5066

20 CIS-12 – Signal Identification Wiki
https://www.sigidwiki.com/wiki/CIS-12

21 29B6 'Kontayner' OTH Radar – Signal Identification Wiki
https://www.sigidwiki.com/wiki/29B6_%27Kontayner%27_OTH_Radar

22 Link 22 – Wikipedia
https://en.wikipedia.org/wiki/Link_22

23 HF/Shortwave Adoption – Raft Technologies
https://raft-tech.com/hf_shortwave-adoption/

24 Shortwave Trading Part I: The West Chicago Tower Mystery – Sniper In Mahwah
https://sniperinmahwah.wordpress.com/2018/05/07/shortwave-trading-part-i-the-west-chicago-tower-mystery/

25 Commercial Interests Petition FCC for High Power Allocation on Shortwave Spectrum – ARRL
https://www.arrl.org/news/commercial-interests-petition-fcc-for-high-power-allocation-on-shortwave-spectrum

26 ARRL Opposition to RM-11953 (August 2023)
https://www.arrl.org/files/file/FCC%20Documents/ARRL%20Opposition%20FCC%20RM-11953%2008_2023.pdf

27 DRM Broadcast Schedule B26 – Digital Radio Mondiale
https://schedule.drm.org/

28 DRM Broadcast Schedules Updated for B26 – DRM Consortium
https://www.drm.org/drm-broadcast-schedules-updated-for-b26/

29 Chinese 30-tone OFDM modem – Signal Identification Wiki
https://www.sigidwiki.com/wiki/Chinese_30-tone_OFDM_modem

30 Proceeding RM-11953 History Report – FCC ECFS
https://ecfsapi.fcc.gov/reports/history/RM-11953

31 Jump Trading, Virtu and the 'hidden optical fibre cable' – Financial Times
https://www.ft.com/content/099342e4-cae8-4ac7-86bd-a3f2048065e8

Researched and written with claude-opus-5-5, from the sources listed above. Figures are as reported by those sources. Exported November 29, 2026 from https://intel.innerpulse.net/doc/commercial-and-military-hf-digital-modes-in-2026-hfdl-gmdss-dsc-stanag-4285-ale, where the current version lives.