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INTERNATIONAL ELECTROTECHNICAL COMMISSION
INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE (CISPR)

Subject: Radio Services below 150kHz

The following document has been submitted by IARU on the subject of radio services below 150kHz.

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CIS/B/WG1 TF WPT

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE (CISPR)

SUB-COMMITTEE B: INTERFERENCE RELATING TO INDUSTRIAL, SCIENTIFIC AND MEDICAL (ISM) RADIO-FREQUENCY APPARATUS, TO OTHER (HEAVY) INDUSTRIAL EQUIPMENT; TO OVERHEAD POWER LINES; TO HIGH VOLTAGE EQUIPMENT AND TO ELECTRIC TRACTION

WG 1: INDUSTRIAL, SCIENTIFIC AND MEDICAL (I.S.M.) RADIO FREQUENCY APPARATUS

TF WPT: Wireless Power Transfer Task-Force

Radio Services below 150 kHz

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1 Introduction

During the last taskforce meeting only very few radio services operating below 150 kHz were listed out of delegates' heads. However since it is CISPRs main task to protect radio reception in the frequency range from 9 kHz to 400 GHz, the group needs a full knowledge on which services exist.

2 Frequency usage in VLF and LF ranges (9 to 150 kHz)

2.1 VLF transmitters

The following table was copied from Wikipedia on 11th Mai 2015 from "http://en.wikipedia.org/wiki/Very_low_frequency" and shows radio transmitters below 25 kHz.

Callsign	Frequency	Location of transmitter	Remarks
-	11.905 kHz	Russia (various locations)	Alpha-Navigation
-	12.649 kHz	Russia (various locations)	Alpha-Navigation
-	14.881 kHz	Russia (various locations)	Alpha-Navigation
HWU	15.1 kHz	Rosnay, France	400 kW.
-	~~15.625 kHz~~	~~-~~	~~Frequency for horizontal deflection of electron beam in CRT televisions (576i)~~
-	~~15.734 kHz~~	~~-~~	~~Frequency for horizontal deflection of electron beam in CRT televisions (480i)~~
JXN	16.4 kHz	Gildeskål (Norway)	
SAQ	17.2 kHz	Grimeton (Sweden)	Only active at special occasions (Alexanderson Day)
-	~~ca. 17.5 kHz~~	~~?~~	~~Twenty second pulses~~

NAA	17.8 kHz	VLF station (NAA) at Cutler, Maine	
RDL/UPD UFQE/UPP/UPD8	18.1 kHz	Russia (various locations including Matotchkinchar, Russia	
HWU	18.3 kHz	Le Blanc (France)	Frequently inactive for longer periods
RKS	18.9 kHz	Russia (various locations)	Rarely active
GBZ	19.6 kHz	Anthorn (Britain)	Many operation modes.
NWC	19.8 kHz	Exmouth, Western Australia (AUS)	Used for submarine communication, 1 Megawatt.
ICV	20.27 kHz	Tavolara (Italia)	
RJH63, RJH66, RJH69, RJH77, RJH99	20.5 kHz	Russia (various locations)	Time signal transmitter Beta
ICV	20.76 kHz	Tavolara (Italia)	
HWU	20.9 kHz	Saint-Assise, France	
RDL	21.1 kHz	Russia (various locations)	rarely active
NPM	21.4 kHz	Hawaii (USA)	
HWU	21.75 kHz	Rosnay, France	
GBZ	22.1 kHz	Skelton (Britain)	
-	22.2 kHz	Ebino (Japan)	
-	22.3 kHz	Russia?	Only active on 2nd of each month for a short period between 11:00 and 13:00 (respectively 10:00 and 12:00 in winter), if 2nd of each month is not a Sunday
RJH63, RJH66, RJH69, RJH77, RJH99	23 kHz	Russia (various locations)	Time signal transmitter Beta
DHO38	23.4 kHz	near Rhauderfehn (Germany)	submarine communication
NAA	24 kHz	Cutler, Maine (USA)	Used for submarine communication, at 2 megawatts.
NLK	24.6 kHz	Seattle, Washington (USA)	192 kW.
NLF	24.8 kHz	Arlington, Washington (USA)	Used for submarine communication.

2.2 LF time signal stations for radio clocks

40 kHz	JJY	Japan	Mount Otakadoya, Fukushima	Capacitance hat, height 250 m	50 kW	Located near Fukushima and from Mount Hagane (located on Kyushu Island).
50 kHz	RTZ	Russia	Irkutsk		10 kW	Inactive.
60 kHz	JJY	Japan	Mount Hagane, Kyushu	Capacitance hat, height 200 m	50 kW	Located on Kyūshū Island.
	WWVB	United States	Near Fort Collins, Colorado[4]	Two capacitance hats, height 122 m	70 kW	Received through most of mainland USA.
	MSF	United Kingdom	Anthorn		17 kW	Range up to 1500 km. Before 1 April 2007, the signal was transmitted from Rugby, Warwickshire.
66.66 kHz	RBU	Russia	Taldom, Moscow		10 kW	55° 44' N, 38° 12' E

68.5 kHz	BPC	China	Shangqiu, Henan		90 kW	21 hours per day, with a 3 hour break from 05:00–08:00 (China Standard Time) daily (21:00–24:00 UTC).
~~75 kHz~~	~~HBG~~	~~Switzerland~~	~~Prangins~~		~~20 kW~~	Discontinued as of 1 January 2012.
77.5 kHz	DCF77	Germany	Mainflingen, Hessen	Vertical omni-directional antennas with top-loading capacity, height 150 m	50 kW	Located southeast of Frankfurt am Main with a range of up to 2000 km
	BSF	Taiwan	Zhongli			
100 kHz	BPL	China	Pucheng, Shaanxi		800 kW	LORAN-C compatible format signal on air from 5:30 to 13:30 UTC, with a reception radius up to 3000 km.
162 kHz	TDF	France	Allouis	Two guyed steel lattice masts, height 350 m, fed on the top	2000 kW	AM broadcast with auxiliary timecode modulation

2.3 Other LF Services (incomplete list)

90 - 110 kHz	Loran-C, eLoran	worldwide	Navigation and timing
129.1 kHz	DCF49	Germany	Ripple control
135,6 kHz	HGA22	Germany	Ripple control
135,7 - 137,8	Amateur Radio	worldwide	
139 kHz	DCF39	Germany	Ripple control
147.3 kHz	DDH47	Germany	Weather fax

3 Protection requirements

3.1 Protection of low frequency radio services against interference from inductive SRDs

The European Union decision on short range devices (Office Journal of the EU, L334/17-36, 13.12.2013) proposes field strength limits for inductive short range devices (SRD's), including wireless power transfer (e.g. chargers). In the LF range, the proposed limit is generally 72 dBµA/m at 10 m up to 100 kHz, and -66 dBµA/m to 150 kHz. Considering a r^{-3} range dependence of magnetic near-fields, this is approximately equivalent to the 1998 ICNIRP reference (7 A/m = 137 dBµA/m) at a distance of 0.6 m. Thus it seems that the proposed SRD limit has apparently only been guided by human SAR (specific absorption rate) exposure considerations, and effectively serves as an undesirable deregulation regarding radio spectrum compatibility.

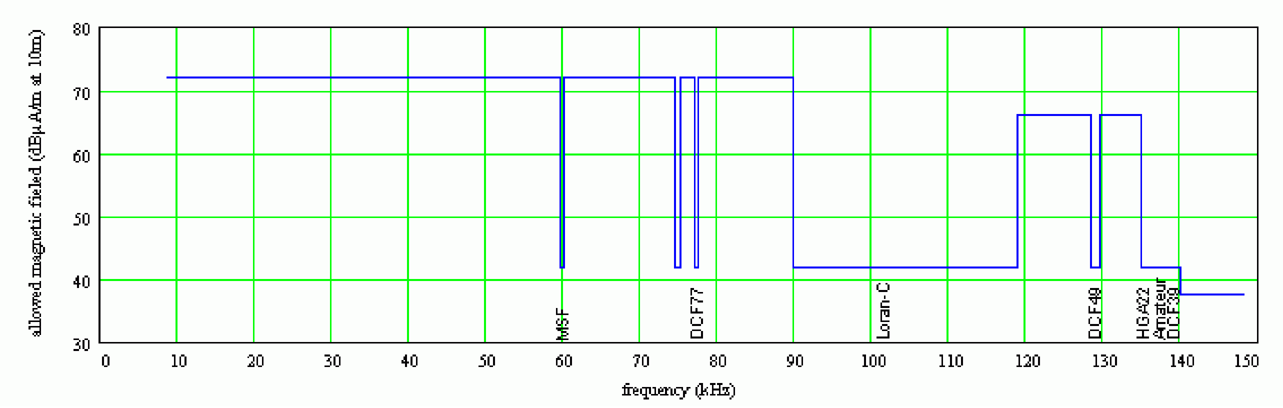

Fig.1: Proposed fieldstrength limit in European directive on low-frequency inductive devices

To provide minimal protection for a few (but not all) existing radio services, 30 dB notches (down to 42 dBµA/m) have been included around a few discrete frequencies: Time signals at 60, 75 and 77.5 kHz, Loran-C at 90-119 kHz, EFR ripple control and LF amateurs at 129 and 135-140 kHz.

At the reduced limit, the radiated far-field power is quite small, on the order of 0.4 nanowatt near 140 kHz. However with the expected wide-spread use of inductive SRD's, relatively small near-field distances between sources (e.g. wireless charging devices in many households) and radio receivers (e.g. DCF77 clocks, amateurs) are likely to occur very frequently. The calculations below will demonstrate that under these (rather typical) circumstances, the protection of existing radio services (especially the amateur service) is by far not adequate. Interference exceeding the natural noise floor by several orders of magnitude would have to be expected.

Furthermore, considering the unique propagation properties of the LF range, new long range radio applications (like enhanced Loran-C) may appear in the future. Thus a decision to allow inductive devices to pollute of a large part of the spectrum may not be wise in the long term, and it will be very hard to revoke after millions or billions of short range devices have been deployed. As low frequency magnetic fields penetrate buildings with little attenuation, cumulative far-field power from such a large number of devices could potentially build up to several watts, significantly raising the noise floor across a whole continent.

There are low-frequency SRD applications like wireless power transfer, which need to work with relatively high magnetic field strength, but are not used to convey data at any significant rate. Thus they could be confined to a narrow bandwidth (e.g. less than 100 Hz). For this purpose, a few dedicated narrow channels should be set apart, in analogy to the ISM bands (industrial, scientific, medical usage) at HF frequencies.

On the other hand, for devices intended for communication which require more bandwidth but less power, wider spectral ranges could be defined. But these would still need to be restricted both in frequency and in field strength, well below the current preposition. Preferably emission masks should then be defined in terms of a spectral density, compared to the noise background at expected ranges of potential radio receivers.

3.2 Amateur radio service

The frequency range 135.7 - 137.8 kHz is a secondary allocation to amateurs in most European and many other countries, with a maximum of 1 W ERP (0.55 W radiated power). Several FCC part-5 licenses have been granted in the USA.

There has also been activity in other frequency bands: 73 kHz (former allocation in the UK before 2002, not available now), 74 kHz and 29 kHz (USA part-5), below 9 kHz (a few dedicated Eu and US experimenters). Note that similar considerations regarding the 472-479 kHz MF band would be appropriate, but this is beyond the scope of this paper.

Due to the challenges of radiating and receiving a low frequency signal, there are not many active amateurs (currently probably about 100 in Europe). But in this group one will find mostly skilled operators, usually with a deep interest in physics, electronics, radio propagation, and signal processing. All equipment has to be home-brewed, and dedicated software is being developed.

Often these individuals feel that the purpose of their activities is more towards experimentation and exploring physical limits, rather than exchanging standard or contest-style amateur communication. On LF, we find an inspiring and educative combination of Marconi's historic radio art with novel and advanced digital signal processing technologies.

The LF range allows employing different propagation modes with unique properties: Daytime groundwave (stable, low attenuation ~ 2dB/100km over land), daytime skywave (D-layer reflection, broad maximum at noon), nighttime skywave (E-layer multiple hops, intercontinental long-range propagation). Interestingly, the magnetic field component can penetrate buildings and reach significantly into the ground (e.g. for cave radio).

LF amateurs can usually generate only small radiated power. They are limited by regulations (1 watt ERP), but even more by the physically small dimensions of antennas in residential areas (~ 15 m), relative to the wavelength (2200 m), providing a typical radiation efficiency on the order of 0.1 %.

Innovative ultra-sensitive receive techniques with very low detection bandwidth have been developed, making use of the phase stability of LF radio paths (eg "visual slow Morse" on spectrograms with a few milliHz FFT bin width, or correlation techniques for digital message detection). Some receive amateurs operate online "grabbers", showing updating spectrograms for quasi-realtime feedback to transmit experimenters. On a quiet day, a transmission with one microwatt radiated power can be detected at about 200 km groundwave range within about a minute.

Besides the natural background noise, amateurs have to cope with a large variety of man-made interference. In central Europe, two powerful primary users (stations HGA22 and DCF39 operated by the EFR) provide strong and continuous adjacent signals (3 to 10 mV/m), with significant in band FSK-modulation products which render part of the band unusable to amateurs. At night, the carriers are accompanied by AM sidebands due to ionospheric intermodulation (the “Luxembourg effect”). There are also military FSK transmitters like SXV (135.8 kHz, Greece) and occasionally CFH (137.0 kHz, Canada). In addition, amateur receivers in suburban areas often suffer from local interference from badly filtered switch-mode power supplies (e.g. energy saving lamps or AC adapters).

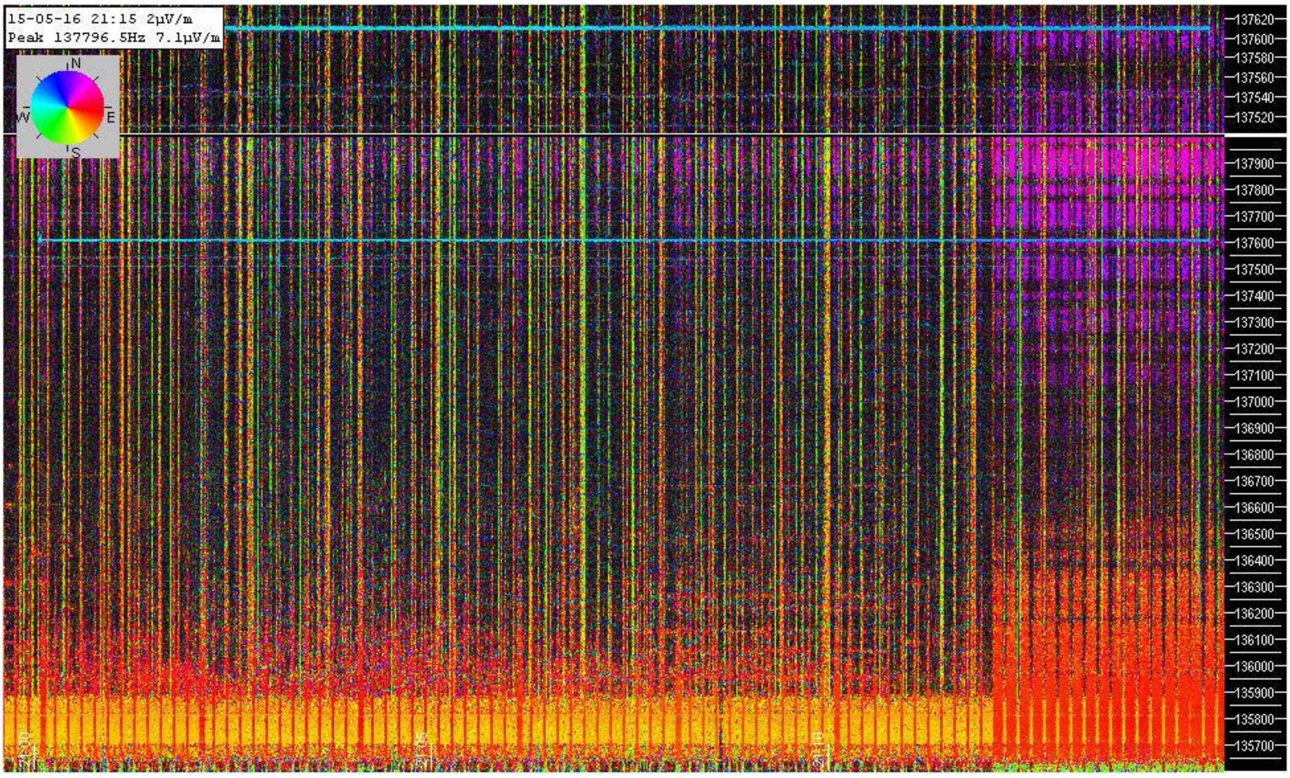

Fig. 2: Colour spectrogram from the DF6NM directional grabber (from http://df6nm.de/grabber/Grabber.htm). The direction of arrival is measured using electric and magnetic antennas on a dual-channel receiver, and converted to colour (as indicated by compass inset). Vertical axis corresponds to frequency from 135.6 to 138 kHz (with a zoomed section at the top), horizontal time scale is one second per pixel. The horizontal blue-green line at 137.61 kHz is a 15-minute WSPR data sequence, sent by amateur station DK7FC in Heidelberg.

The purple vertical bars coming in from the top are due to splatter from periodic DCF39 telegrams (139 kHz, Burg, Germany). Since 2007, a new transmitter installation is apparently using unshaped FSK modulation, creating an unnecessarily wide spectrum. The density of telegrams has increased after 21:12 UT. Red bars near the bottom are FSK telegrams from HGA22 (135.6 kHz, Budapest, Hungary), with an upper frequency of 135.77 kHz. Red horizontal patterns are Luxembourg effect modulation impressed on the HGA22 carrier. The yellow horizontal band near the bottom is continuous FSK from SXV (135.8 kHz Marathon, Greek navy). Coloured wideband vertical bars are spherics, caused by lightning events impinging from different directions.

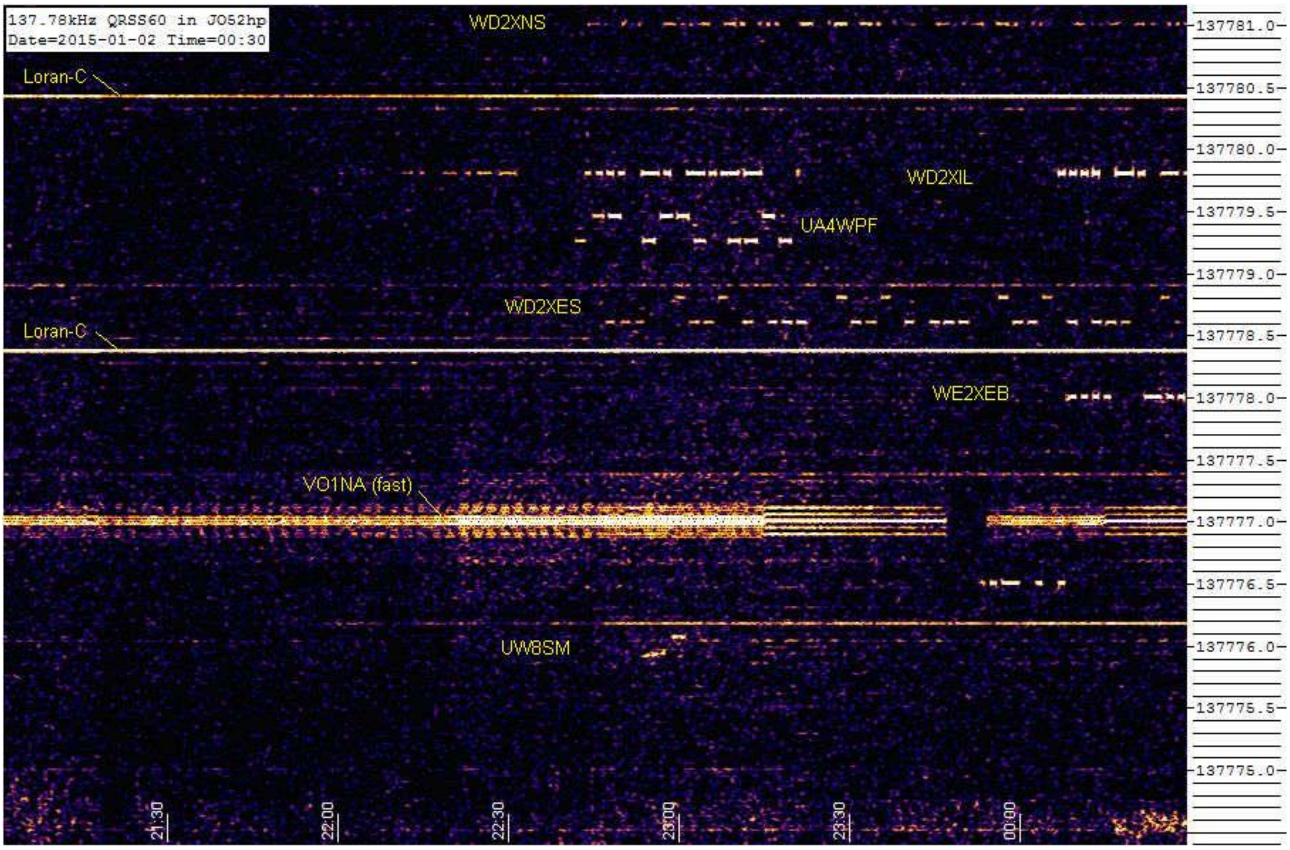

Fig. 3: Narrowband spectrogram showing transatlantic slow-Morse signals from several American and other amateur stations, received around 137.778 kHz by Hartmut Wolff in Germany using a K9AY cardioid antenna (from https://dl.dropboxusercontent.com/u/50178231/137.778kHz-Grabber.jpg). Scales: 11.5 millihertz FFT bins, 15 seconds per pixel.

3.3 Protection of the amateur radio service

In the context of potential SRD emissions, the amateur radio service is especially sensitive to local interference, primarily for two reasons:

1. There is nothing like a minimum guaranteed usable signal strength, as amateurs often try to receive the weakest signals down to the background noise floor. On a quiet day in Europe, natural background noise is around 0.05 µV/m in 1 Hz bandwidth (E_n = -26 dBµV/m/sqrtHz, equivalent to H_n = -77.5 dBµA/m/sqrtHz using E/H = 377 ohms).

However the natural noise floor can be very variable, predominantly due to lightning activity (e.g. 30 dB higher in a summer night). Other fixed services usually employ high radiated power (e.g. 100 kW) to safely overcome atmospheric statics and achieve near 100% link availability. This means that under low natural noise conditions, they have a large SNR margin, and higher tolerance to local interference.

On the other hand, amateurs are willing to "sail with the wind", i.e. usually try to make best use of any currently available SNR. Naturally the best opportunities occur at times of low background noise. Thus degradation effects from continuous local interference need to be evaluated with reference to the lowest natural noise levels.

2. Amateurs typically have to operate from suburban residential areas. This means that the receive antennas are not far away from their neighbors. For example, the DF6NM online spectrogram ("grabber") uses electric and magnetic receive antennas at the edge of a small garden (Fig. 4). There are about twenty neighbor parties within 30 m distance, well within the reactive nearfield which extends to $\lambda/2\pi$ = 350m at 137 kHz.

Fig 4: DF6NM LF receive antennas in a suburban neighborhood in Nuernberg (from Google Maps)

Although the power radiated by a SRD into the far field is rather small (~ 0.4 nanowatts), a very significant field strength will occur within the reactive nearfield zone. Unfortunately inductive SRDs like wireless chargers can be expected to be permanently used in many households. Thus we have to carefully view their magnetic and electric near field components in relation to the natural noise level from the far field.

We will now consider an inductive device delivering an axial field of 42 dBµA/m at 10 m. The quasistatic magnetic field decays with distance as r^{-3} (ie -60 dB/decade), out to -51 dBµA/m at the far field boundary. The circumferential field component in the loop plane is half of that, i.e. -57 dBµA/m at 350 m. At the boundary, this component will then become the far field, decaying by -20 dB/decade from there on. E and H will be proportional to each other (E/H = Z0 = 377Ω). To quantify local magnetic interference to a loop antenna versus natural noise from the far field, 0 dBµA/m is equivalent to +51.5 dBµV/m.

An electrical (whip) receive antenna is not directly sensitive to magnetic fields. But the quasistatic magnetic nearfield is accompanied by an induced electric field. Theoretically this goes up with r^{-2} (40 dB/decade) as we move back in from the far field boundary. Thus interference of an inductive source to a whip is weaker than to a loop, but still not negligible. Note also that considering not perfectly symmetrically fed SRD coils and potential coupling to conducting structures in the house environment, electrical near fields may be even stronger than what pure dipole theory would predict.

The field components from a small magnetic dipole source are

$$H\alpha(r,\alpha) := \frac{iA}{4\cdot\pi}\cdot -\cos(\alpha)\cdot\left(\frac{1}{r^3}+\frac{jk}{r^2}+\frac{jk^2}{r}\right)\cdot\exp(-jk\cdot r)$$

$$Hr(r,\alpha) := \frac{iA}{4\cdot\pi}\cdot 2\cdot\sin(\alpha)\cdot\left(\frac{1}{r^3}+\frac{jk}{r^2}\right)\cdot\exp(-jk\cdot r)$$

$$E\phi(r,\alpha) := Z0\cdot\frac{iA}{4\cdot\pi}\cdot\cos(\alpha)\cdot\left(\frac{jk}{r^2}+\frac{jk^2}{r}\right)\cdot\exp(-jk\cdot r)$$

r: distance, α: angle from loop plane (90° = coil axis), Hr and Hα: radial and transverse magnetic fields, Eϕ: transverse electric field, jk = jω/c = j$2\pi/\lambda$, iA: magnetic dipole moment (current*turns*coil area), Z0 = 377Ω

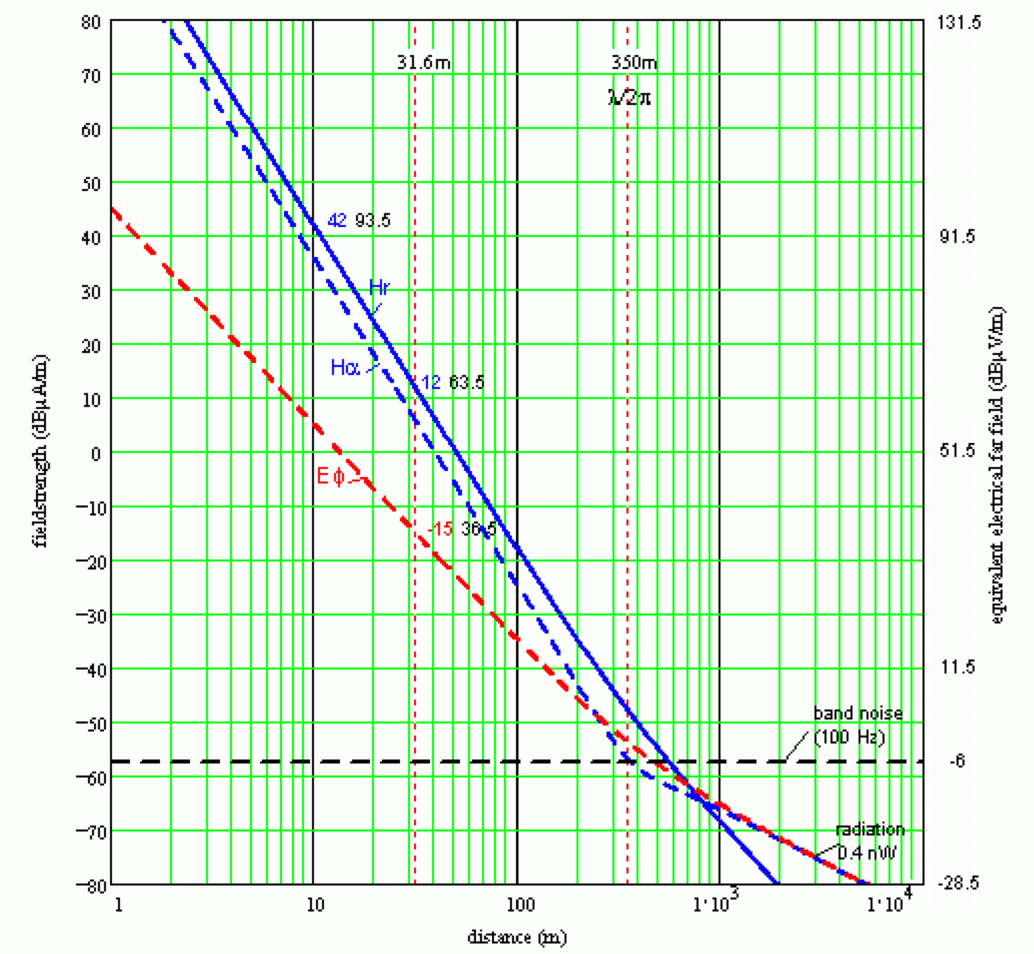

Fig 5: Magnetic and electric fields around a 137 kHz magnetic dipole source with 42 dBµA/m at 10m. Blue line: axial magnetic field, blue and red dashes: transverse magnetic and electric fields (in equator plane), black dashes: natural daytime noise floor in 100 Hz bandwidth. Note that the offset scale on the right side indicates the equivalent electrical far-field (dBµV/m) for a given magnetic field (dBµA/m).

To estimate the noise floor increase, we have to make assumptions on the distance and the bandwidth of the interferer. Assuming 31.6 m distance, the field strength of the SRD will be 42 - 3*10 dBµA/m = 12 dBµA/m, equivalent to a far-field signal of 63.5 dBµV/m. Note that this is a very strong signal, comparable to DCF39 at a distance of 500 km! If we assume the interference is spread out 100 Hz wide, it would compare to a natural noise level of -26+20 = -6 dBµV/m. Thus the amateur's noise level would go up by 69.5 dB - obviously a dramatic increase!

To have negligible impact, we would want to bring the interference down to about 10 dB below the natural noise, which means that the maximum tolerable SRD field strength would need to be reduced by about **80 dB** (ie. -38 dBµA/m instead of +42 dBµA/m at 10m, a factor of 10000).

The amateur might consider mitigating the interference by using an electrical receive antenna (e.g. active whip). Note that this would already be a compromise as advantages from figure-eight or cardioid directivity would no longer be available. At the assumed distance, he could reduce the interference by 6+20*log(350/31.6) = 27 dB, or 36.5 dBµV/m. This leads to a maximum acceptable SRD strength of -11 dBµA/m at 10 m, still **53 dB** less than the current European preposition.

Amateur antenna	Bandwidth of SRD		
	1 Hz	100 Hz	10 kHz
Loop (H-field)	100 dB	**80 dB**	60 dB
Whip (E-field)	73 dB	53 dB	33 dB

Table of required reduction (relative to a baseline of 42 dBµA/m at 10 m), to achieve negligible interference to an amateur antenna at 32 m distance

Note that although spectral spreading of the interference may seem to alleviate the problem, in real life it tends to make the situation much worse. For an amateur experimenter, it is often possible to circumvent a strong but narrowband interferer by asking the transmitter to adapt the operating frequency. On the other hand, a wideband noise source cannot be evaded. This situation is felt painfully today with switch-mode power supplies, whose chopping frequency is often frequency-modulated across several kHz due to poor line voltage filtering.

Conclusion: To summarize, we have to conclude that for sufficient protection of the LF amateur service, the emission limits of inductive devices around 136 kHz would need to be reduced by up to around 80 dB. As this cannot be practically achieved by modifications of coil designs, the consequence is that this frequency range will need to be avoided completely.

3.4 Time signals

For example, DCF77 at 77.5 kHz can be received with about 1 mV/m (60 dBµV/m, 8.5 dBµA/m) at the edge of the coverage area (800 km). The SNR required to reliably decode the AM time signal is about 12 dB.

Radio controlled clocks usually employ ferrite loop-stick antennas. They are potentially placed in the same household as e.g. wireless charging devices, thus we assume a distance of 5 m and optimal antenna orientations. Thus the maximum tolerable interference would be 8.5-12 = -3.5 dBµA/m. Scaling from 5 m to 10 m (18 dB), we conclude that the SRD should emit less than -21.5 dBµA/m at 10m. This is **63.5 dB** (a factor of 1500) less than the proposed 42 µA/m limit.

3.5 LF ripple control network (Europäische Funk-Rundsteuerung, EFR)

A very similar situation can occur for the EFR receivers at 129.1, 135.6 and 139 kHz, which have been installed in large numbers e.g. for tariff switching purposes. They are also typically using ferrite loop-stick antennas deployed in the basement of a house, potentially only a few meters from the nearest wireless charger. Like with DCF77, the currently proposed limit would need to be reduced by more than **60 dB**.

3.6 Loran-C

The Loran-C pulsed navigation system is still being used in many countries, occupying approximately the frequency range 85 - 115 kHz. Recently an enhanced version "eLoran" has been suggested, which augments the basic system with precalibrated terrain-dependent phase maps (ASF, additional secondary factor) and unambiguous time encoding. This will enable a reliable high-power backup in case of loss of GPS availability. In addition, favorable and complimentary properties (like indoor or urban canyon reception with magnetic antennas) suggest the use of combined satellite and eLoran PNT systems (precision navigation and timing). When using ASF maps, spatial and temporal uncertainty is solely limited by available SNR.

At 100 kHz, natural best background noise is around -23 dBµV/m/sqrtHz. At 30 kHz bandwidth, this is about +22 dBµV/m or -29.5 dBµA/m. In an urban situation, we might again assume an -42 dBµA/m interfering inductive device at a distance of 31.6 m, producing +42-30 = +12 dBµA/m. This would increase the noise by 41.5 dB, and degrade precision by a factor of 120. At five times larger distance (160 m), the interference would still be equal to the noise (ie. 3 dB degradation). To have neglegible degradation at 32 m, the limit needs to be lowered by **52 dB**.

3.7 SAQ – World heritage VLF alternator transmitter

Most VLF transmitters below 40 kHz are intended to serve submerged submarines which will surely be well outside the nearfield of a SRD home application. A notable exception is the historic Alexanderson alternator which occasionally operates on 17.2 kHz from a heritage site at Grimeton (Sweden). The bi-annual Morse transmissions are intended for radio enthusiasts and have regularly been reported by several hundred listeners worldwide.

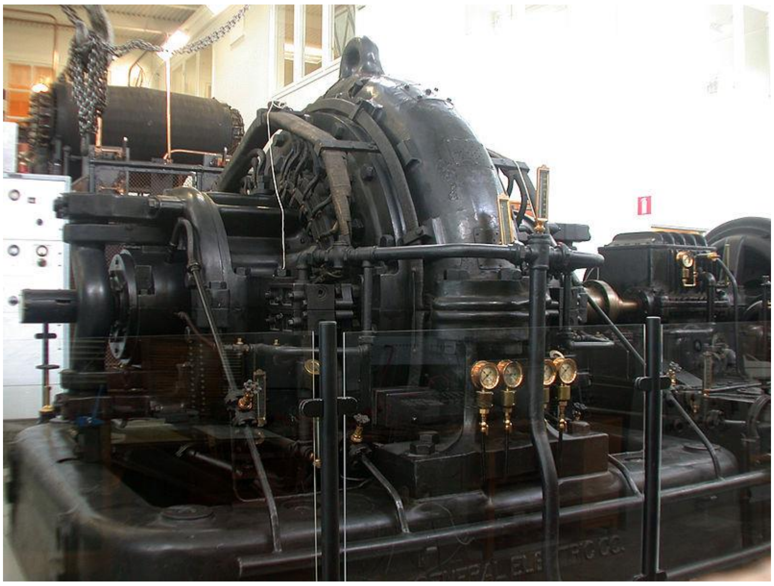

Fig 6: Historic alternator at SAQ (from https://de.wikipedia.org/wiki/Datei:Alexanderson_Alternator.jpg)

Again, the receivers are typically located in residential areas, not far from potential inductive power transfer devices. At this frequency, no notch has been declared so the SRD's would be allowed to emit 72 dBµA/m at 10 m, or 42 dBµA/m at 31.6 m.

Assuming a natural background noise of around 1 µV/m in 1 Hz, and 100 Hz bandwidth for Morse reception, the noise floor would be +20 dBµV/m or -31.5 dBµA/m. Thus interference from a co-channel SRD placed at 32 m would be **73.5 dB** above the noise, obviously defeating any attempt to hear the historical transmitter.

3.8 VLF amateur experimenters

In 2014 a group of American amateurs were granted an FCC part-5 permission to operate at VLF frequencies below 30 kHz. Transmissions from two of them (Bob Raide, WH2XBA/1 and Dexter McIntyre, WH2XBA/4) at 29.5 kHz have been detected by several monitors in Europe. Using slow ASK modulation, the transmissions have been unambiguously identified using a dedicated "Opera deep-search" correlation technique, based on sub-milliHz resolution spectrum data. Like with SAQ, these detections would have been impossible if a co-channel SRD would have operated at the proposed levels within several hundred meters.

In Europe, during the last decade several experimenters have successfully communicated over large distances, using unregulated spectrum at 8.97 kHz and 8.27 kHz (dubbed "Dreamer's band"). Achievable power at a given antenna size and voltage capability is four to five orders of magnitude lower than at 137 kHz. This has been partly compensated by using kite antennas and even smaller FFT bandwidth (down to 47 µHz) with very long coherent averaging. Around New Year 2015, Paul Nicholson in the UK managed to detect 8.82 kHz transmissions from Dexter, W4DEX in North Carolina, using 150 µW radiated power. Paul was even able to decode slow PSK data messages very close to the Shannon limit.

It would be very interesting to allocate a narrow shared amateur slot at 17.2 kHz. Technically, transmitting would be somewhat more efficient and without annoying acoustic side effects, and on the receive side background noise would be lower. Most important, such experiments could nicely augment the educative purpose of the primary user SAQ - imagine that a radio enthusiast could first hear the drifting Morse message from the ancient machine, and then use his sophisticated soundcard DSP receiver to detect a feeble but ultra-stable carrier from a microwatt amateur station!

4. Conclusion

To effectively protect low frequency radio services, the field strength of inductive short range devices needs to be reduced by up to 80 dB below the currently proposed level of 42 µA/m at 10 m. As this is not feasible by coil design alone, it is recommended to restrict inductive power transmission to dedicated and narrow frequency bands which do not overlap with radio services.