European Radiocommunications Committee (ERC)
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# SHARING BETWEEN INDUCTIVE SYSTEMS AND RADIOCOMMUNICATION SYSTEMS IN THE BAND 9 - 135 kHz

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## EXECUTIVE SUMMARY

In November 1994 ETSI published I-ETS 300 330 on Short Range Devices (SRDs): "Technical characteristics and test methods for radio equipment in the frequency range 9 kHz to 25 MHz and inductive loop systems in the frequency range 9 kHz to 30 MHz". There was a major difference of opinion during the standard preparation on the field strength limit of inductive loop systems in the frequency band 9 -135 kHz. As a consequence two H-field strength limits, 42 dBμA/m at 10 m and 72 dBμA/m at 10 m at 0.03 MHz decreasing at 3.5 dB/octave, were adopted in the standard.

PT SE24 was tasked to study the compatibility issues in the band 9 - 135 kHz between inductive loop systems and primary radio services, and also between inductive systems with different field strength levels.

SE24 collected information on existing primary services and also on inductive loop systems. The phenomena of magnetic fields were examined.

The project team concluded that there is a risk of interference when:

- a receiver of a primary status service and an inductive system operating at the higher field strength level operate co-channel and within a distance of less than 100 m. This scenario also requires time coincidence and that the inductive system operates at the fringe reception area of the primary service;

- inductive systems operating at the two field strength levels operate co-channel within a distance below 100 m.

PT SE24 therefore proposed to divide the band 9 - 135 kHz into sub-bands for the higher and lower field strength levels. This division provides more protection for certain primary services and also for inductive loop systems with the lower field strength level. The proposal leads to an increased availability of spectrum, because the band can be shared in an efficient way between various services, especially since the band is not heavily used in most European countries at present.

The division into sub-bands would not change the primary status of the current primary services in the whole 9 - 135 kHz band. If an inductive system causes harmful interference to primary service users, the operator of the inductive system is responsible for removing the interference.

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# 1 INTRODUCTION

In November 1994 ETSI published I-ETS 300 330 on Short Range Devices (SRDs): "Technical characteristics and test methods for radio equipment in the frequency range 9 kHz to 25 MHz and inductive loop systems in the frequency range 9 kHz to 30 MHz". There was a major difference of opinion during the standard preparation on the field strength limit of inductive loop systems in the frequency band 9 -135 kHz. As a consequence two H-field strength limits, 42 dBμA/m at 10 m and 72 dBμA/m at 10 m at 0.03 MHz decreasing at 3.5 dB/octaveave, were adopted in the standard.

Following the publication of I-ETS 300 330, some administrations indicated that they would not accept equipment with the higher field strength level. Project Team SE24 was tasked to study the sharing possibilities from the technical point of view and, if needed, to propose a division of the frequency band 9 - 135 kHz into sub-bands, where the two different field strength levels could be used.

# 2 BACKGROUND

## 2.1 Present regulations

The regulations for inductive systems are different in various CEPT countries. In some countries this equipment is not considered as radio equipment, and neither type approval nor limits for the magnetic field are set. In other countries inductive equipment is considered as radio equipment and there are various national type approval standards. The definition of the field strength, the limits, and the measurement methods, are not harmonised.

The inductive systems operate on a non-interference basis as defined in Radio Regulations (RR). Both existing and future primary services can claim protection from any interference caused by inductive systems.

Although CEPT Recommendation T/R 01-04 does not cover the inductive loop systems, some administrations had adopted the spurious emissions limit of T/R 01-04 as a guideline when assessing the limits for these systems.

## 2.2 The requirements of the primary services

The different types of primary and secondary services, as defined in the ITU Radio Regulations, were identified. These types were grouped into generic types, which have similar protection needs:

<u>Maritime radio navigation / Mobile</u>
-These services are protected. They do not, however, require special protection from inductive short range devices because the receivers are located at greater than 100 m distance from the inductive loop systems.

<u>Aeronautical radio navigation</u>
- Similarly, these services do not require special protection from inductive loop systems because the receivers are located at greater than 100 m height from the inductive systems. At low heights the ILS or similar systems are used.

<u>Land radio navigation</u>
- The receivers of these systems are mobile and any interference is both localised and temporary. There would not be any significant degradation in the service caused by inductive systems.

<u>Fixed, point to point communication</u>
- These systems operate between dedicated, defined sites. They have high quality receivers, which could be protected by distance and site engineering due to their location.

<u>Fixed, point to multi-point communication</u>
- There are a number of systems, which have a single point transmitter with multiple receivers. The location of the receivers is not specific and often not known in advance. Examples of this type of system are Time Clocks and Utility Control. Special protection at lower power levels may be required for these systems.

Referring to these groups, it is obvious that only fixed point to multi-point types of primary service need additional protection from inductive loop systems. One example of fixed point to multi-point service is the DCF77 time clock, which three administrations had indicated to need specific protection.

## 2.3 The reasons for operating in the frequency band 9 - 135 kHz and the spectrum requirement

A main reason for using the frequency band 9 - 135 kHz is the unique propagation characteristic. It enables inductive systems, receivers and transponders, to operate without the "line of sight" requirements of higher frequencies. This benefit is also useful for the primary services, although their main consideration is the very wide area coverage.

Primary radio services in this band transmit a signal designed to propagate under far-field conditions, this means 20 dB/decade roll-off with distance.

Inductive systems operate under near-field conditions, with 60 dB/decade roll-off with distance. It enables the systems to generate reasonably high field strength levels close to the transmitter while not producing a propagating (Hertzian) wave of any significance. The low frequency provides object penetration, which can be utilised for instance as anti-theft applications. It also enables the use of small transponders without batteries.

<u>The need for spectrum in 9 - 135 kHz for inductive devices</u>

The term 'short range inductive devices' actually covers several distinct markets that have widely differing requirements. These include:

| | |
|---|---|
| car immobilisers | access control |
| animal identification | proximity sensors |
| alarm systems | retail anti-theft systems |
| cable detection | data transfer to handhold devices |
| personnel identification | automatic article identification |
| waste management | wireless control systems |
| wireless voice links | automatic road tolling |

There are also several different technologies available to address these needs. The differing combinations of market need and technology solutions lead to a variety of specific products tailored to the constraints of each market. The different technology solutions are generally optimised by design into several overlapping frequency bands.

The following paragraph describes some of the constraints that lead to the varied frequency designs. Some call for the use of low frequencies, and some for high frequencies. Others lead to choices of specific intermediate frequencies, and at least two technologies require low levels of wideband fields.

Physical constraints and design considerations include:

- Many applications require reading through metal (e.g. anti-theft). This encourages lower frequencies for penetration (higher skin depth);

- The induced voltage and the voltage gain from using high Q resonant circuits increases with frequency ($Q = 2\pi fL/R$);

- The frequency of ferromagnetic-tag systems should be kept low to avoid high material coercivity, which would force the need for higher excitation strength ($H_C$ proportional to frequency$^{1/2}$);

- The return signal from passive RFID (Radio Frequency Identification Device) and anti-theft tags is very low, so frequencies already used by for example radio, computer monitor emissions and switched-mode power supplies, must be avoided;

- Magneto-mechanical resonators must be of a length (1- 3 cm) suitable for the market;

- Higher frequencies are favoured by the use of miniature circuit components, which are essential for example in animal identification. Equally, lower chip costs can be achieved with lower on-chip tuning capacitances (giving higher frequency operation);

- For very-low-cost-tags used in the biggest markets, component tolerancing does not allow narrow system bandwidth. Equally, some systems use broadband (40 kHz) signals, which have low interference potential because of the very low duty cycle and energy on any specific frequency. Only broadband systems can currently address markets (e.g. airline baggage) for very-low-cost ID;

- For emerging Read/Write markets, the need to transmit data to the transponder gives an increased transmitter bandwidth requirement, of up to several kHz;

- Some common applications require different products to be co-located: this can necessitate the use of non-coincident operating frequencies.

Since different sub-markets place different emphasis on penetration, or tag cost, or read rate, or error rate, or tag size, the resulting optimisation frequencies are distributed throughout the spectral range.

## 2.4 Sharing between inductive systems and primary services in the band 9 - 135 kHz

During the preparation of standard I-ETS 300 330 some administrations expressed their strong concern over the potential interference which inductive systems might cause to current and future planned primary radio services. Other administrations did not consider the sharing with primary services a particular problem. In many countries the frequency band 9 - 135 kHz is not heavily used. Also many of the primary radio services, for example the maritime navigation service, are used in such a way that provides sufficient geographical separation.

## 2.5 Sharing between inductive systems with different field strength levels

Some manufacturers of inductive systems were concerned over the potential interference risk between inductive systems having different transmitter field levels. A compromise was reached within ETSI after the transmitter field strength limit had been reduced to 72 dBμA/m at 0.03 MHz decreasing at 3.5 dB/octave. It is noted that about half of the existing inductive systems operate with a field strength value higher than determined in I-ETS 300 330.

PT SE 24 determined that a risk for interference between co-channel inductive systems exists, if the systems operate within a distance smaller than 100 m to each other. Various techniques including site engineering can be used to avoid problems.

## 2.6 Inductive loop systems and phenomena of a magnetic field

Inductive loop systems address commercial and industrial applications divided into two main categories:

loop coil transponder systems with coverage of about 1 - 2 m

An identified item is equipped with a small transponder, a tag. The transponder can be a passive L/C circuit or a mechanical resonator. It can, as well, be an active transponder, which is powered either by a battery or by the received field. Since the re-radiated field from a transponder can be very low due to a small physical size, the practical communication distance is below 2 metres.

large size loop systems with coverage area about a few thousand square metres

Large size inductive loop systems are used in short range communications applications, where a large multitude is receiving the same information. The information transmitted can be digital or analogue, optionally addressed individually or as groups by call codes. The most popular applications comprise in-building communication systems, for example conference halls, simultaneous translation equipment, churches, noisy industrial environments, support for partially deaf people, on-site paging, etc.

Both types can operate with any type of modulation with a constant amplitude or a pulsed carrier. Typical applications are normally for indoor use with the equipment installed in a fixed location.

The operating frequency is determined by the transponder technology used. Lowest cost transponders may use mechanical embedded material, which has its best performance on the lowest frequencies in the range 25 - 135 kHz. Systems using L/C resonating transponders are using frequencies around 70 kHz - 8 MHz due to lower ambient man-made noise level. Frequencies above 8 MHz do have further limitations as the field attenuation approaches 20 dB/decade for distances larger than $\lambda/2\pi$.

Large size loop communication systems are transmit-to-receive communication systems, where multiple receivers are used instead of transponders. These systems are operating on a single frequency above 20 kHz.

The required magnetic field strength is determined by the ambient noise level and total path loss. The total path loss of a passive small transponder system can exceed 100 dB in 1 metre range. A fast attenuation is characteristic for the magnetic field. The emitted field has a purely reactive near field ($d < \lambda/2\pi$), which attenuates theoretically according to 3rd order with distance or 60 dB/decade. The potential co-channel interference to primary services is negligible at a distance of approx. 100 m. Since the low frequency magnetic field has a good penetrating capability, the inductive technology is most suitable in certain applications, for example anti-theft systems.

Although the power limits in regulations (e.g. T/R 01-04) are usually expressed in Watts or dBμV/m, these units are not practical for inductive systems due to the negligible radiated power. The transmitter is usually specified by the antenna current or the magnetic field strength (dBμA/m) at a certain distance.

# 3 THEORETICAL STUDY

## 3.1 Magnetic field requirements for loop coil systems

Transmitter field

The measured transmitter field depends on the magnetic dipole parameters of the coil antenna:

A = coil physical size
N = number of coil turns
I = coil input current
d = distance from antenna
f = frequency (when d < $\lambda/2\pi$)

The magnetic field H (A/m) of a circular transmitting loop antenna can be calculated as (d >> coil radius):

$$H = \frac{NIA}{2\pi d^3}$$

The product N I A is also called a Magnetic dipole moment M of the coil.

Transponder radiated field

The level of a radiated field from the transponder received by the interrogator is dependent on the following transponder parameters:

physical size
material properties
distances from the transmitter and the receiver antennas
orientation in the field
frequency

The magnetic radiated field at distance d from the transponder can be calculated as:

$$H_{rx} = H_{tx} \frac{V_{eff}}{2\pi d^3}$$

where $V_{eff}$ is the effective volume of the transponder. $V_{eff}$ can vary significantly between different technologies and is not identical to the real volume.

For most applications the transponder is required to be as small as possible. This makes the radiated field very low and, due to the limited effective volume of a transponder, the field attenuation even in the dominant direction will be at least 100 dB at 1 m distance.

In many applications it is not possible to control the physical orientation of the transponder to be optimal. Therefore the orientation loss, the order of which is 6 - 8 dB, has to be taken into account in the system calculation.

The ambient noise level

The ambient noise is dependent on the location of the equipment. Most equipment is used in commercial and industrial environments, where the ambient noise, especially below 135 kHz, is very high. The main noise sources are the harmonics of different electric equipment, for example switch mode power supplies, PC‘s and TV sets, fluorescent lights, electric distribution in general, etc. The noise level in an industrial environment, measured in a 1 kHz bandwith, varies in the range 5 - 30 dBμA/m at 50 kHz. A typical level is 13 dBμA/m. The noise level falls at 3.5 dB/octave and it is typically -13 dBμA/m at 8 MHz.

<u>The receiver sensitivity</u>

The receiver sensitivity depends on the ambient magnetic noise level. For a reliable operation, 6 - 8 dB S/N ratio shall be assumed.

<u>Required transmitter magnetic field strength for an inductive loop coil system</u>

The system description:

| | |
|---|---|
| transponder distance from a receiver: | 1 metre |
| ambient noise floor: | 13.5 dBμA/m |
| orientation loss of a tag: | 8 dB |
| transponder effective volume: | 100 $cm^3$ |

The system calculation:

| | |
|---|---|
| Ambient noise at 50 kHz: | 13.5 dBμA/m |
| Required S/N: | 8 dB |
| Transponder orientation loss (receive): | 4 dB |
| <u>Receiver min. field level:</u> | 25.5 dBμA/m |
| Transponder loss for $V_{eff}$ =100 $cm^3$: | 97 dB |
| Transponder orientation loss (retransmit): | 4 dB |
| <u>Required transmitter field at 1 m:</u> | 126.5 dBμA/m |
| <u>Required field for 1.4 m x 0.4 m transmit antenna converted to 10 m</u>: | 69.5 dBμA/m |

On the basis of a system calculation, the required transmitter field is 69.5 dBμA/m at 10 m. At 30 kHz the noise level is 2.5 dB higher and the same calculation results in 72 dBμA/m at 10 m, which is the higher limit of I-ETS 300 330.

## 3.2 Interference from inductive systems to primary radio services

ITU Radio Regulations (RR) allocates the frequency band 9 - 135 kHz to certain radio services with primary status. In addition to those primary radio services, administrations allow other applications on a non-interference and non-protection basis. Therefore inductive systems can be allowed to operate in the above mentioned band, if no harmful interference to primary services will occur.

The limit of spurious emissions can be applied as a limit of non-interference use. The CEPT Recommendation T/R 01-04 sets a 65 dBμV/m / 200 Hz at 30 m (13.5 dBμA/m) limit for spurious emissions in the band 15 - 135 kHz, which corresponds to a H-field limit of 42 dBμA/m at 10 m. This means that inductive applications could cause interference to radio services at a distance of up to 30 m. If the transmit carrier of an inductive system is 72 dBμA/m, the higher limit value of I-ETS 300 330, the interference radius is increased to approximately 100 m, when the roll-off factor of the H-field is the theoretical 60 dB/decade.

In addition to co-channel operation, the interference from inductive loop systems to primary radio services depends on many probability factors, for example time-co-incidence, location criticality, typical average field strength level, average field directivity, local EMI noise factor, fringe area factor (ratio of country-average to the minimum primary service signal amplitude), etc.

# 4 FIELD MEASUREMENTS

PT SE24 carried out field measurements in order to find out the roll-off attenuation of H-field and the co-channel interference to a radio system. The measurements were carried out by the FTZ in Berlin and by the French PTT in Paris. The project team also had access to test results from Texas Instruments (D) and TNO Physics and Electronics Laboratory (NL).

## 4.1 The roll-off attenuation of H-field

All the reports prove that the theoretical attenuation of 60 dB/decade correlates well with the practical measurements. However, it was perceived that for certain installations free space conditions may not apply, for example near metal doors or metal window frames. Then the field attenuation is subject to the antenna design and the proximity of the antenna to the metalwork. It was also noted that free space conditions may not apply, when mains or telephone cables run close to the antenna. Inductive loop antennas can induce into metal constructions a current which can be carried over a significant distance and cause a much reduced rate of attenuation. On the other hand, the proximity of metal construction can also cause shielding.

<u>Fields With Distance</u>

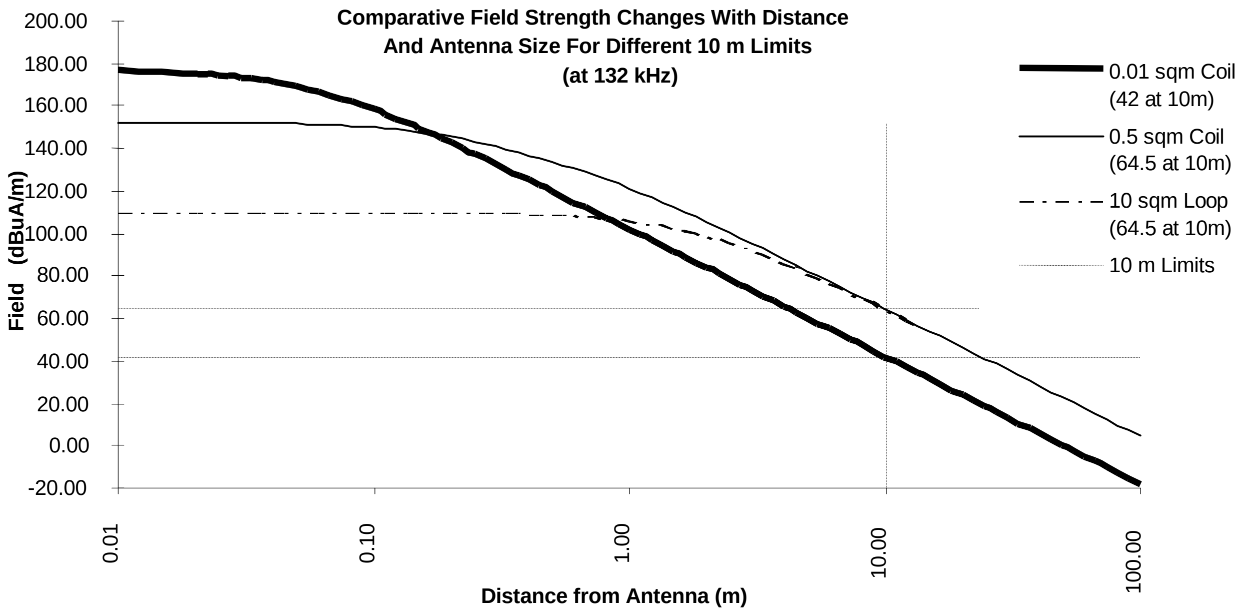
One of the particularly unique features of inductive fields is the relationship between the field close-in to the transmitting loop antenna, the field at 10 m and the size of the antenna itself. The diagram on the next page shows how the field in the 0 to 1 m range varies in relation to the antenna size.

This is generated from the equation for the field strength (H) at distance (d) perpendicular to the centre of a rectangular shaped loop antenna with sides a and b, wound with N turns carrying a current I:

$$H = \frac{NIab}{4\pi\sqrt{(a/2)^2 + (b/2)^2 + d^2}} \left( \frac{1}{(a/2)^2 + d^2} + \frac{1}{(b/2)^2 + d^2} \right) A/m$$

The field level close-in to the antenna is significantly more dependent on the antenna size than on the field defined at 10 m. A consequence of this is that the close-in field for a larger loop, operating at the higher 10 m limit, is less than that generated by a smaller coil, operating at the lower 10 m limit. Using larger loops can reduce the possibility of inductive coupling into close-by metallic structures, cables and other devices. It was also noted that larger loops could not be used where only the lower limit was allowed. The close-in field levels generated in this case could not provide good transponder operation and the benefits could be lost.

The I-ETS 300 330 considers this effect and provides an additional restriction for smaller loops resulting in a lower field strength limit close to the transmit antenna.




## 4.2 The co-channel interference to a radio system

Practical tests were carried out in Berlin, in January 1995, to determine the frequency separation needed to remove the possibility of interference to the primary service receivers (operated by Deutsche Telekom) from inductive systems. A minimum acceptable gap of 1 - 2 kHz was found to be necessary to achieve this.

The interference created by pulsed modulation, when a pulse length is greater than 5 ms, was no less harmful than a continuous carrier system. Therefore the measurement receiver bandwidth for the inductive equipment is proposed to be changed from the current I-ETS 300 330 value of 9 kHz for the band 30 - 135 kHz to 200 Hz in the whole 9 - 135 kHz band. When the pulse length is shorter than 5 ms, an averaging rule, which takes into account the pulse length, should be used.

# 5 CONCLUSIONS

The frequency band 9 - 135 kHz is useful, because of the unique propagation phenomena. Primary services use these frequencies under far field conditions (wide coverage area), inductive applications under near-field conditions (high close-in field strength with a negligible propagating wave).

The numbers of inductive systems is increasing rapidly. At the same time the numbers of primary radio services using this band is generally decreasing, with the exception of Germany, as the services are moving towards higher frequencies.

The units of power / field strength limits are usually expressed in Watts or dBμV/m in ITU and CEPT regulations. These limits should also be expressed in dBμA/m, at least on the lower frequencies, to take into account the measurement methods and the characteristics of inductive equipment.

Although the interference probability from inductive systems to primary radio services is low, interference may occur, when systems operate co-channel within 100 m distance. There is also a risk of interference between inductive systems operating co-channel with different field strength levels within 100 m distance. Such problems are normally solved by site engineering or different system techniques, for example special modulation schemes, TDMA, synchronisation, special antenna design and / or shielding.

SE24 proposed to divide the frequency band 9 - 135 kHz into sub-bands in order to minimise the risk of interference and to ensure enough suitable frequencies for both services (see note below); the higher field strength level would be allowed in the bands:

9 - 70 kHz
119 - 135 kHz.

To be able to carry out this proposal, the measuring receiver bandwidth for inductive equipment in I-ETS 300 330 is proposed to be changed from the current value of 9 kHz at 30 - 135 kHz to 200 Hz in the whole band 9 - 135 kHz

A division into sub-bands would not change the status of the primary radio services: inductive applications operate on a non-protected and non-interference basis. To avoid interference all suitable site-engineering means should be used by all parties involved.

Note: In Germany the higher limit would only be allowed in the bands:

57 - 67 kHz
119 - 127 kHz