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## Recap of the Principles Employed in NFC

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In order to be able to look at the idea of near-field communication (NFC) in its proper context, this chapter offers a summary of the main physical principles used in NFC, which must be remembered throughout this book.

### **1.1. The physical fundamentals of “contactless” and NFC**

To aid in the understanding of the specific problems of these applications, for readers who are unfamiliar with the technical details (or who need to refresh their memories), let us give a brief reminder here about radiofrequency (RF) communications, and describe unambiguously what the term NFC covers. It is physics; not marketing. Hence, it is necessary to review some of the theoretical and physical bases of the technical side of NFC.

#### **1.1.1. *Phenomenon of propagation and radiation***

Let us look at some of the conclusions on the physical concept of propagation of an RF electromagnetic (EM) wave in the classic case of radiation of a simple “Hertzian doublet”. Later on, we will use this simple example to aid an examination of concrete cases of NFC.

### 1.1.2. Classification of fields and spatial regions

When studying the phenomenon of propagation and radiation of EM waves, the Maxwell equations tell us that the values of the radiated electric field  $E$  and magnetic field strength  $H$  depend notably on three main parameters:

- the variable time  $t$ ;
- the variable distance  $r$  from the radiation source, defined in terms of  $1/r$ ,  $1/r^2$  and  $1/r^3$ . If one or more of these terms is negligible in comparison to the other(s), the equations may be simplified;
- the product  $kr$ , equal to:  $kr = 2\pi/\lambda$ .

### 1.1.3. Spatial regions

In the case of a very small antenna (whose sphere equivalent to the radiation source has a very small diameter), it is customary to define three spatial regions known, respectively, as the near-field, intermediary-field and far-field zones depending on the possible values of  $r$  in relation to the value of the wavelength  $\lambda$  at which the system operates – related to the value of  $r$  is greater or lesser than:

$$\frac{1}{k} = \frac{\lambda}{2\pi}$$

### 1.1.4. Far field: $r \gg \lambda/2\pi$ (Fraunhofer zone)

In the far field zone, the terms in  $1/r^2$  and  $1/r^3$  present in the Maxwell equations become negligible, and the values of the fields  $E$  and  $H$  shrink in  $1/r$ . This occurs when the distance  $r$  is greater than a few  $\lambda/2\pi$ . What happens at this point is that we move from a region of quasi-stationary waves to a region of wave propagation, and thus to a regime of radiated field. The electrical field  $E$  is predominant, and there can no longer be any magnetic coupling. Generally, in this zone, devices work by using the radiating field  $E$ , so use a dipole antenna.

### 1.1.5. *Intermediary field: $r$ approximately equal to $\lambda$ (Fresnel zone)*

In this spatial region, all the terms in  $1/r$ ,  $1/r^2$  and  $1/r^3$  are equally preserved. Here, we are in the presence of a radiating near field, where the Fresnel component exists when the antenna's primary dimension is larger than the transmission wavelength  $\lambda$  but the distance  $r$  is approximately equal to  $\lambda$ .

### 1.1.6. *Near field: $r \ll \lambda/2\pi$ (Rayleigh zone) and the origin of NFC*

In the spatial region where  $r \ll \lambda/2\pi$  – *irrespective of the frequency at which the system operates* – i.e. often in the immediate or near surroundings of the antenna, the values of the terms in  $1/r^2$  or  $1/r^3$  are far greater than those of the terms in  $1/r$ , and the fields ( $E$ ,  $H$ ) decrease very quickly. This near-field zone – often called the Rayleigh zone – essentially corresponds to the region of a “(more or less) coupled transformer” (where the received power  $P_r$  is basically equal to the transmitted power  $P_t$ , unlike the effect of free space propagation, where  $P_r \ll P_t$  (far field)).

When the transmission takes place very near to the antenna, the electrical field is generated by the antenna's own potential: this is the near-field domain. At this distance, we see a regime of “quasi-stationary” waves, and it is then possible to establish magnetic or electrical coupling between a tag and the source.

Generally, in this zone, devices work by using the magnetic field  $H$  by inductive coupling, i.e. use a loop antenna, which is the case with NFC.

To summarize:

$$\text{near field (magnetic coupling)} < \frac{\lambda}{2\pi} < \text{far field (wave propagation)}$$

### 1.1.7. *Remarks on contactless, RFID and NFC applications*

These general remarks are of fundamental importance for remote-powered systems (when the transmitted wave provides enough energy for

the tag to function). For existing semi-conductor technologies and the regulations in force, as a preliminary point, it is always interesting to know the regions of the near-field and far-field zones for which the contactless/RFID/NFC application is intended to function. With this in mind, let us look at Table 1.1, which indicates the relations between the values of the frequencies and the distances  $\lambda/2\pi$  associated therewith.

	Frequencies	Wavelengths	$\frac{\lambda}{2\pi}$	Near-field zone for NFC application	Start of far-field region $> \sim 3 \lambda$
LF	125 kHz	2,400 m	382 m	Always	1,100 m
HF	13.56 MHz	22.12 m	3.52 m	Always	11 m
UHF	433 MHz	69.2 cm	11.02 cm	0 to $\sim 12$ cm	24 cm
	866 MHz	34.6 cm	5.51 cm	0 to $\sim 6$ cm	18 cm
	915 MHz	32.8 cm	5.22 cm	0 to $\sim 5.5$ cm	17 cm
	2.450 GHz	12.2 cm	1.94 cm	0 to $\sim 2$ cm	6 cm
SHF	5.890 GHz	5.1 cm	0.8 cm	0 to $\sim 1$ cm	3 cm

**Table 1.1.** Relations between the values of frequencies and the distances  $\lambda/2\pi$  associated therewith

As this table illustrates, in ultra high frequency (UHF) and super high frequency (SHF), most of the time the operating distances required/possible for RFID applications (for example, reading of labels on pallets of goods) are significant (several meters). Given that these distances are always much greater than the value of  $\lambda/2\pi$ , the UHF tags used for RFID work in the “far field”, and therefore must use principles other than that of magnetic coupling to communicate with the base station – for instance, they could exploit the phenomenon of propagation of EM types and backscattering of the received waves.

However, in the low frequency (LF) and high frequency (HF) bands, the operational distances required/possible for the applications – for technological reasons, because of the regulations in force, the possibilities of remote powering and cost factors – are always much smaller than the value of  $\lambda/2\pi$ . In this case, the devices operate and communicate in the “near field”.

Since their first applications in LF and HF (particularly at 13.56 MHz), contactless chip cards and RFID tags communicating at 125 kHz and/or 13.56 MHz operate in the “near field”, and therefore (to paraphrase Molière, in *The Bourgeois Gentleman*) have been operating NFC all their lives and did not even know it. Thus, in terms of its principle, in LF and HF, NFC is not intrinsically any great leap forward. Hence, the applications are based on principles which primarily involve inductive loops and inductive/magnetic coupling.

## 1.2. The concept of NFC

Let us now examine the physics of the applicational concept of NFC.

In 1999, the two main leaders in the semi-conductor market – Philips Semiconductors (a Dutch company, which has since become NXP) after having bought out the Austrian company Mikron); and Japan’s Sony (the respective creators of the patented designs for contactless chip cards MiFare™ (based on the international norm ISO 14443 part A) and FeliCa™ (conforming to the Japanese norm JIS X6319-4)) – came together to co-invent the concept of NFC for multiple, generic and varied applications for digital data, and not to supplant or compete with chip-card applications as many people believe. Hence, NFC was born around the year 2000.

To conclude this brief introduction, if readers still believe that NFC is synonymous only with mobile telephony, they are wrong, as proved by the following text from “Scope” (late 2002), an introduction to the norm ECMA 340 NFC IP1, which was to become ISO 18092:

“Near Field Communication Interface and Protocol (NFCIP-1) defines communication modes using inductive coupled devices operating at the center frequency of 13.56 MHz for interconnection of computer peripherals. It also defines both the active and the passive communication modes of NFCIP-1 to

realize a communication network using NFC devices for networked products and also for consumer equipment”.

### 1.2.1. Biot–Savart law

Having clearly defined NFC and demonstrated its position in relation to other technologies, let us now give a recap of the physical theoretical minimum of what needs to be recalled to gain a detailed view of what is flowing through the coils and loops of antennas and what we are talking about throughout this book. We must remember that an NFC device only works if layer 1 – the *physical layer* in the OSI model – works properly. This involves:

- the creation of a magnetic field  $H$ ;
- the evolution of that field with distance.

The law, known as the Biot–Laplace and Biot–Savart law, establishes the mathematical relation which exists between a current  $I$  circulating in an element of an electric circuit of length  $dl$  and the intensity of the magnetic induction  $B$  as a function of the distance  $x$  existing between the measured point (of unit vector  $u$ ) and the oriented element  $dl$  producing the field, according to the formula:

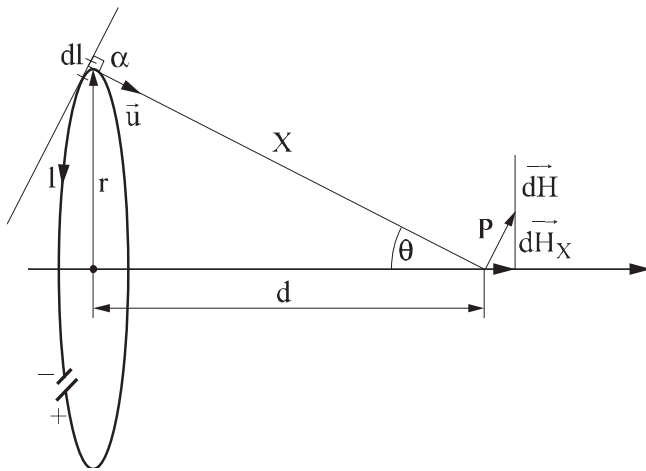
$$dH = \frac{(I dl) \wedge u}{4 \pi x^2}$$

$$\text{so that } B = \mu \times H = \frac{(\mu I)}{4 \Pi} \oint \frac{dl \wedge u}{dx^2}$$

where  $\oint$  is the curvilinear integral calculated on the length  $l$  and  $\wedge$  is the notation of the vector product.

### 1.2.2. Field $H$ at a point on the axis of a circular antenna

In the particular case of a flat circular antenna, with radius  $r$ , at a point  $P$  situated at a distance  $d$  along the axis of the antenna (Figure 1.1).



**Figure 1.1.** Field  $H$  at a point on the axis of a circular antenna

We can write:

$$dH = (I dl) \wedge u / 4\pi x^2$$

and hence:

$$dH = (I dl \sin \alpha) / 4\pi x^2$$

As, in this case:

$$\alpha = \pi/2 \text{ and } \sin \alpha = 1$$

so:

$$dH = I dl / 4\pi x^2$$

On the axis of the coil, the component  $dH_x$  of  $dH$  is equal to:

$$dH_x = I dl \sin \theta / 4\pi x^2 \text{ and } x = r / \sin \theta$$

and hence:

$$dH_x = I \sin^3 \theta dl / 4\pi r^2$$

In addition, at a distance  $d$  along the axis of the coil:

$$x = \sqrt{(r^2 + d^2)} \text{ and } \sin^3 \theta = r^3/x^3$$

so:

$$\sin^3 \theta = r^3/(r^2 + d^2)^{3/2}$$

which gives us:

$$dH_x = [(I/4\pi) \times (r/(r^2 + d^2)^{3/2})] \times dl$$

Thus, definitively, by now integrating that simple integral in  $dl$  along the whole length of the circular spire of length  $2\pi r$ :

$$H_x = [(I/4\pi) \times (r/(r^2 + d^2)^{3/2})] \int_0^{2\pi r} dl$$

we obtain:

$$H(d, r) = \frac{I r^2}{2(r^2 + d^2)^{3/2}}$$

Furthermore,  $B = \mu H(d, r)$ :

$$B(d, r) = \mu \times \frac{r^2}{2[(r^2 + d^2)^{3/2}]} I$$

EXAMPLE 1.1.– In the air, with  $\mu = \mu_0 = 4 \times 3.14 \times 10^{-7}$ :

$$\text{– if } H = 1 \text{ A/m} \quad \text{then} \quad B = \mu_0 \times H = 1.256 \mu\text{T};$$

$$\text{– if } B = 1 \mu\text{T} \quad \text{then} \quad H = B/\mu_0 = 0.796 \text{ A/m}.$$

It should be noted that for  $d = 0$  and a coil of  $N$  spires, we see the same, well-known formula for the induction  $B$  in the center of a flat circular coil:

$$B(0, r) = \mu \frac{N I}{2 r} = \mu H(0, r)$$

### 1.2.3. Decrease in the field $H$ as a function of “ $d$ ”

By setting:

–  $d$  as the distance between the center of the antenna and the measuring point on the axis;

–  $r$  as the radius of the antenna;

–  $a = d/r$  and  $d = (a r)$ .

The above relation between  $H_0$  (in the center of the base station antenna) and  $H_d$  becomes:

$$H(a, r) = \frac{1}{[(1 + a^2)^{3/2}]} \times H(0, r)$$

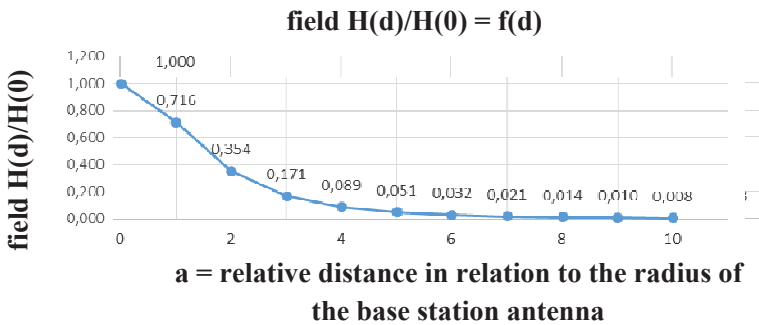
The ratio  $H(a, r)/H(0, r)$  depending on the values of  $r$  and  $d$ , or indeed on the values of the ratio  $a = d/r$ , are shown in Table 1.2 (for a given value of  $r$ , the table indicates the values of the corrective factor “ $(1+a^2)^{3/2}$ ” and its inverse as a function of the ratio  $a = d/r$ ).

$d$	$a$	$H(0,r)/H(a, r) = (1 + a^2)^{3/2}$	$H(a, r)/H(0,r)$	$= 1/(1 + a^2)^{3/2}$
0	0	$\sqrt{1}$	= 1	= 1
0.5 r	0.5	$\sqrt{1.953}$	= 1.397	= 0.716
r	1	$\sqrt{8}$	= 2.828	= 0.354
1.33 r	1.33	$\sqrt{21.34}$	= 4.62	= 0.216
1.414 r	1.414	$\sqrt{27}$	= 5.196	= 0.192
1.5 r	1.5	$\sqrt{34.33}$	= 5.86	= 0.170
1.66 r	1.66	$\sqrt{53.8}$	= 7.34	= 0.136
2 r	2	$\sqrt{125}$	= 11.8	= 0.0847
3 r	3	$\sqrt{1000}$	= 31.62	= 0.0316
4 r	4	$\sqrt{4913}$	= 70	= 0.0143
4.5 r	4.5	$\sqrt{9595}$	= 98	= 0.0101
5 r	5	$\sqrt{17576}$	= 132	= 0.0076

**Table 1.2.** Variations of the ratio  $H(a, r)/H(0, r)$  depending on the values of “ $r$ ” and “ $d$ ”

NOTE.– We will frequently refer back to this table as it is very relevant throughout the book.

Figure 1.2 reflects the results given in this table.

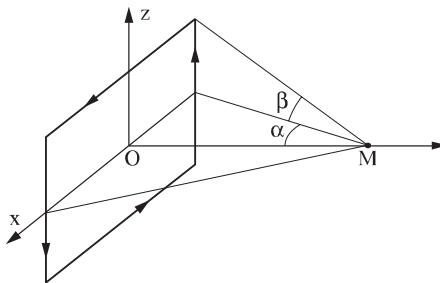


**Figure 1.2.** Curve of the variations in the ratio  $H(d)/H(0)$  at “a”

EXAMPLE 1.2.– For an antenna of an initiator/reader (proximity coupler device (PCD)) ISO 10 373-6, so of radius  $r = 7.5$  cm (diameter = 15 cm) we switch from a 7.5 A/m field at 0 cm to a 1.5 A/m field (i.e. a ratio of 5), when the ratio of the distance between the antenna of the PCD (reader) and the proximity integrated circuit card (PICC) (target) is around ( $1.4 \times$  the radius of the PCD), which is a distance of  $1.4 \times 7.5 = 10.5$  cm. On principle, a PCD yielding a magnetic field  $H(0)$  of 7.5 A/m can read all ISO PICCs (because it needs to be sensitive to at least 1.5 A/m minimum) from 0 cm to around 10.5 cm.

#### 1.2.4. Field $H$ at a point on the axis of a rectangular antenna

Similarly, in the case of a flat, rectangular antenna with sides  $a$  and  $b$ , with  $N$  spires, at a point  $M$  situated at a distance  $x$  on the axis of the antenna (Figure 1.3).



**Figure 1.3.** Field  $H$  at a point on the axis of a rectangular antenna

After a few lengthy calculations, we obtain:

$$H = \frac{N \times I \times a \times b}{4 \times \pi \times \sqrt{\left(\frac{a}{2}\right)^2 + \left(\frac{b}{2}\right)^2 + x^2}} \times \left( \frac{1}{\left(\frac{a}{2}\right)^2 + x^2} + \frac{1}{\left(\frac{b}{2}\right)^2 + x^2} \right)$$

After these few physico-theoretical examples, let us now examine the detailed calculations of NFC initiator and target antennas.

