Technical E-Paper

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# Antenna design and atmospheric electrical phenomena.

## PART TWO: protective devices.

Francesco Zaccarini

Atmospheric electrical phenomena and their often devastating effects do not only affect the radiocommunications sector.

Regulations and procedures exist aimed both at identifying protective measures to adopt for people, structures and systems, and at carrying out a correct risk assessment for the purpose of the safety of property and people.

So, as regards antennas and their design, we will present a brief overview of this topic, divided into two parts.

PART ONE:
Which atmospheric electrical phenomena can cause damage to telecommunications systems?

PART TWO:
What protection devices can be used in an antenna system and/or in an antenna itself?

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## 3. Protection devices external to the antenna.

Although we will focus here only on the antennas, it should be noted that the antenna’s primary protection is the structure on which it is mounted; that is, by how it is effectively protected from these atmospheric events.

As far as the antenna itself is concerned, an *external type of protection* is represented by those devices which, installed on the transmission line near the antenna or at other points along the line itself, eliminate charge accumulation and/or introduce a preferential (low inductance) path to ground.

These devices are:

- Lightning arrestors;
- Short-circuited stubs or reactive elements;
- Bleeding resistors.

***Figure 3.1***
Arrestor in the open air at the base of an insulated tower (monopole).

### 3.1. Lightning arrestors

Lightning arrestors are devices that use two suitably sized electrodes, in the open air or inserted in a capsule filled with inert gas, which allow the formation of an electric arc when the potential difference between the two conductors exceeds a pre-set limit.

This device is always installed at a point of the antenna not subject to high RF voltages, such as, for example, the power supply point where the nominal impedance is usually standardized at 50 Ω.

Figure **3.1** shows an example of an arrestor that works in open air, consisting of two metal spheres at the base of a medium wave radiation lattice tower.

The distance between the spheres should be assessed as the shortest gap that allows normal antenna operation at the given transmitting power level.

***Figure 3.2***
Coaxial lightning arrester with N-f connector, that includes an exhaust gas pipe (model SSC_N230 Huber & Shun).

In the case of higher frequency antenna systems, coaxial arrestors like the one shown in **Figure 3.2**, that exploit the gas discharge principle, are used. Different models are available on the market, with different in/out connectors and with replaceable gas discharge cartridges, characterized by different intervention thresholds.

Compared to open air arrestors, those that use gas discharge tubes (GDT) have more stable electrical parameters and exploit the ionization of the gas inside the tube to pass from a condition of high impedance to a state of conduction of the ionized gas, characterized by a resistance of around fifteen ohms.

## 3.2. Short-circuited stubs or reactive elements.

By exploiting the properties of the transmission lines or a discrete component (inductance), it is possible to create a short circuit for the direct current which at the same time presents a high impedance for the RF currents present in the transmission line connected to the antenna.

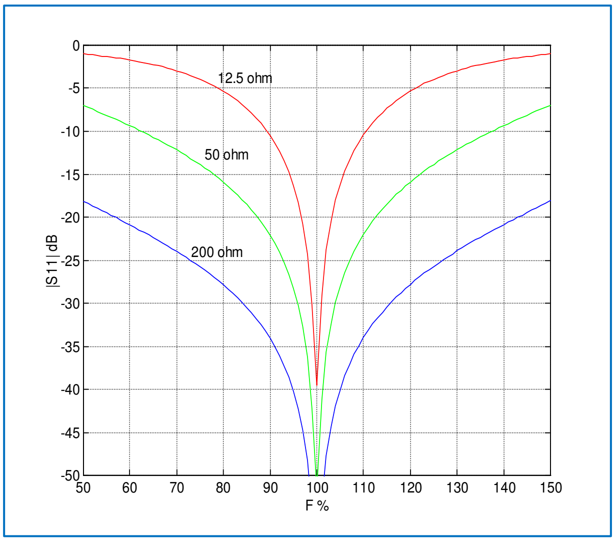

***Figure 3.3***

|S$_{11}$| [dB] of a charge $Z_L$=50Ω to which a quarter- wave stub, with three different characteristic impedance values $Z_0$ is connected.

If a transmission line of length ***x*** and characteristic impedance **$Z_0$** is connected to a charge with impedance ***$Z_L$***, the input impedance ***$Z_{IN}$*** at the line in correspondence with the section opposite to the charge is given by:

$$Z_{IN}(x) = Z_0 \frac{Z_L + jZ_0 \tan\left(\frac{2\pi}{\lambda_g}x\right)}{Z_0 + jZ_L \tan\left(\frac{2\pi}{\lambda_g}x\right)}$$

where $\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_r}}$ is the wavelength in the line. If, instead of the charge, there is a short circuit ($Z_L$ =*0*), the previous equation becomes:

$$Z_{IN}(x) = jZ_0 \tan\left(\frac{2\pi}{\lambda_g}x\right)$$

Expression that diverges to infinity (in practice, to a very high value depending on the losses in the line) in correspondence of:

$$x = \frac{\lambda_g}{4}.$$

Therefore, using a short-circuited section of line (or stub) of this length connected in parallel to the antenna connector (or at another suitably chosen point of the descent path) it is possible to create a device for grounding the radiating element without affecting its VSWR.

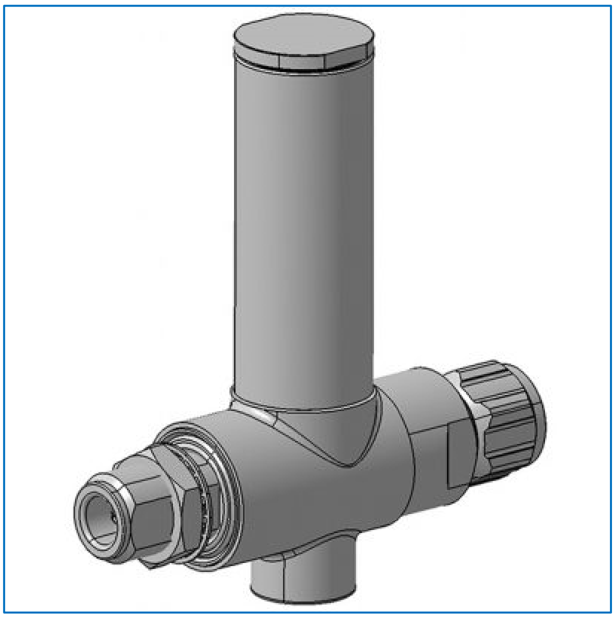

***Figure 3.4***

Example of surge arrestor, N-m/N-f connectorized, with quarter-wave stub in parallel.

Figure **3.3** shows the frequency profile of |S$_{11}$| [dB] (that is, without the sign, the return loss) of a charge with value $Z_L$ =*50Ω* to which a stub λ/4 short-circuited at the opposite end is connected in parallel. The three curves refer to the three different characteristic impedance values of the line with which the stub is produced: 12.5 Ω ($Z_L/4$), 50Ω ($Z_L$) and 200Ω ($4 \cdot Z_L$).

As can be seen from the figure, to obtain a greater useful bandwidth it is necessary to design the stub with a characteristic impedance that is greater than the nominal one of the line and antenna to which it is connected, generally 50Ω. From a practical point of view, however, there are physical limits to the feasibility of a coaxial line with an overly high impedance, having to make a very thin central conductor. Figure **3.4** shows an example of a coaxial arrestor with a λ/4 stub parallel to the line, with N-male to N-female connectors.

If a quarter-wave stub is impractical, for example in the HF bands or at lower frequencies, it can be replaced with an inductor of suitable value (*RF choke*), placed in parallel with the *line* or with the antenna input connector leads.

When compared to the short-circuited stub, an inductor still has high reactance not only for the RF current to the antenna but also for any transient currents that vary rapidly over time. For this reason, it is usually used in the place of the discharge resistor to avoid the accumulation of electrostatic charge on the antenna conductors.

### 3.3. Bleeding resistors.

If a stub or inductor is not used, the electrostatic charge buildup described in the previous paragraph is eliminated by inserting a resistor with an *R* value which is much greater than the impedance of the line or antenna.

In this case, the combination of antenna, line and resistor becomes an *RC* circuit, with an *R* value such that the surge rate is greater than the accumulation rate of the electrostatic charge on the antenna conductors.

In large antenna systems, this device is usually coupled to an arc arrestor like the one in **Figure 3.1**.

## 4. Protection devices incorporated in the antenna.

If the resistance between the two contacts of the input connector of a commercial antenna is measured with a multimeter, a value close to 0Ω is almost always found. For the direct current, therefore, there is a real short circuit at the antenna terminals, and this protects the radio-electric equipment connected to it from most of the atmospheric events described above.

As regards what is explained in paragraph 3, the devices that use this protection and that are incorporated in an antenna have two specific characteristics that make them not transparent to the correct functioning of the antenna itself.

Indeed, for these devices it can be said that:

- they are part of the radiating element or of the distribution/adaptation network;
- they also have other functions, such as that of mechanical support.

It is therefore possible to distinguish the following cases.

## *Short-circuited radiating element.*

Numerous types of radiating elements are physically short-circuited, this being a characteristic of the element itself. Furthermore, since these antennas are standing wave ones, in some cases there is a point on the conductor characterized by a zero RF voltage which can therefore be directly grounded on the antenna support structure.

This is the case of the folded dipole of **Figure 3.5**, which is not only intrinsically short-circuited since it consists of a flattened loop with a perimeter equal to λ, but can be electrically connected to ground at the point opposite the power supply, where there is a RF voltage null.

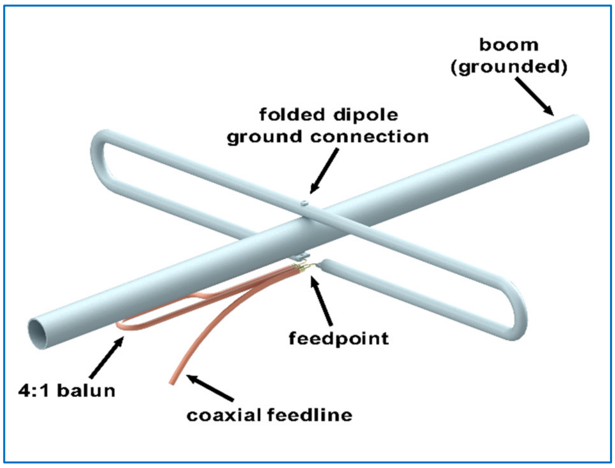

*Figure 3.5*
Folded dipole fed by 4:1 balun in coaxial cable.

In this case, the 4:1 balun in coaxial cable, shown in the figure, from the point of view of protection against electrostatic surges, would not be necessary at all.

Careful analysis of the current (and RF voltage) distribution on a specific radiating structure allows, during the design stage, to choose points that can be suitably grounded without interfering with the radiation and impedance perameters of the antenna.

Unlike the classic folded dipole that more or less everyone knows, the voltage distribution on a radiator does not always have an intuitive trend, and it is therefore necessary to use appropriate electromagnetic simulation software to determine the correct location of the ground point.

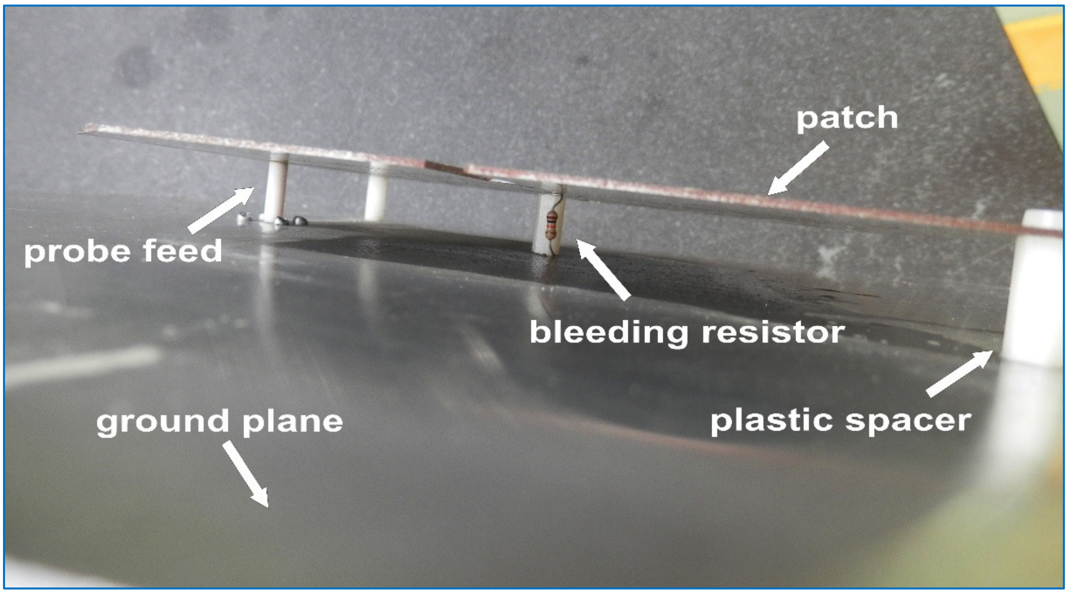

*Figure 3.6*
Patch element for RFID applications in the 900 MHz band (seen from the side), with bleeding resistor positioned in the center.

In the example of **Figure 3.6**, where a patch element positioned on an aluminum ground plane is seen in profile, a *bleeding resistor* to ground is positioned in the center of the element, next to an insulating column.

In this case, theory states that the central point of the patch is at zero RF potential, so the resistance could be eliminated and a short-circuit metal column directly applied.

However, from an operational point of view, since it is an asymmetrical patch, i.e., designed for circular polarization, it is still necessary to verify that any short circuit in the center does not appreciably modify the polarization characteristics (*axial ratio*) of the antenna.

## *Radiating element with short-circuited balun.*

Often in antennas and/or in the radiating elements comprising it, there are circuit elements which implement a short circuit for the direct current and which, at the same time, also have a different function, necessary for the proper operation of the antenna.

An easy example is the log-periodic array in **Figure 3.7** where the bifilar feed line (that also acts as the mechanical support of the dipoles) ends with a shorted stub behind the longest element and mechanically holds the mounting bracket.

From an electromagnetic point of view, the length of this stub, which also acts as a balun, is essential in optimizing the gain curve and any boom resonances in the operating band. It is also an excellent grounding arrangement for all elements of the array, featuring a very low DC resistance to ground.

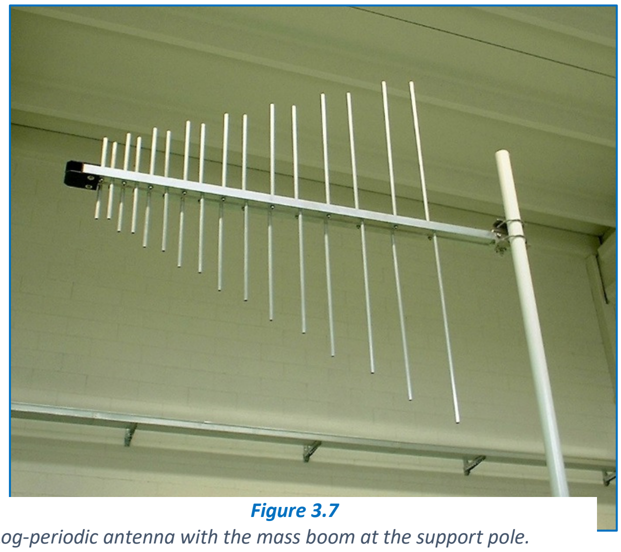

***Figure 3.7***

*Log-periodic antenna with the mass boom at the support pole.*

**Figure 3.8** shows another example, i.e., a radiating element (a dipole) mounted into a panel, at a given distance from a metal reflector.

In this element, the short-circuited stub, which also implements the balun, acts as a mechanical support of the dipole itself on the metal reflector, where it is fixed using rivets.

From a circuit point of view, in this example the stub has a length of less than λ/4 and therefore

***Figure 3.8***

*Dipole of a 2.4 GHz sector panel with mechanical support that acts as a balun.*

produces an inductive reactance in parallel with the feed point of the dipole (in coaxial cable).

This inductive reactance is compensated by a parallel capacitance, obtained by metallizing a tiny PCB board positioned above the dipole itself, and it is an effective spacer as well.

This configuration enables adjustment of the distance between the dipole and the reflector plane to obtain the desired radiation characteristics, and in-band compensation of the reactive components of the dipole itself, significantly improving adaptation.

Also in this case, therefore, the short-circuit device is an integral part of the antenna.

### _Short circuit stub (or RF choke) incorporated in the antenna._

There are some cases where the antenna or radiating elements used for the array have not been designed with short-circuit so distributed components *(stubs in $\lambda/4$)* or discrete components (*RF choke*) must be installed in the antenna.

In the case of a short-circuited stub in $\lambda/4$, one of its fundamental properties is generally considered, consisting in the fact that, if designed for the mid-band frequency $f_0$, it introduces an inductive type reactance for $f<f_0$ and, vice versa, a capacitive reactance for $f>f_0$.

It follows that, according to the impedance curve that the antenna presents, thanks to this system it is possible to introduce an in-band compensation of the reactive components of the element itself.

In this case, however, it is not possible to play on the characteristic impedance of the stub (the lower, the greater the in-band compensation), since a standard coaxial cable is generally used or at most, due to obvious manufacturing limitations, a microstrip of 25 ÷ 75 ohms.

An example is shown in **Figure 3.9**, where a coaxial cable stub is welded in parallel to the feed point of a radiating element on the PCB.

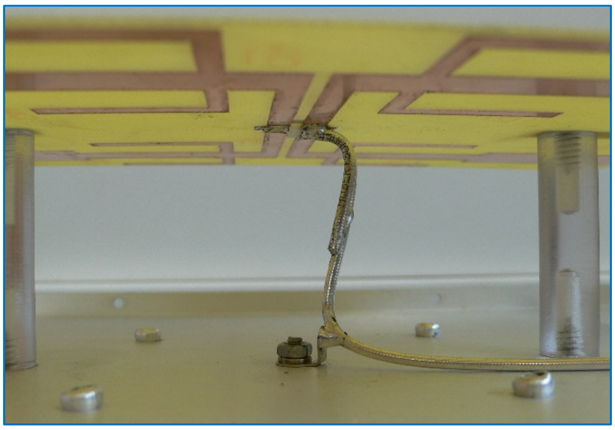

***Figure 3.9***

*Stub in welded coaxial cable parallel to the feed point of a printed circuit radiating element..*

### _Balun and lumped constant impedance transformers._

As already mentioned, the antennas used on frequencies lower than VHF generally consist of thin, extended conductors, isolated from the ground and of a dimension that allows it to be charged with considerable potential differences.

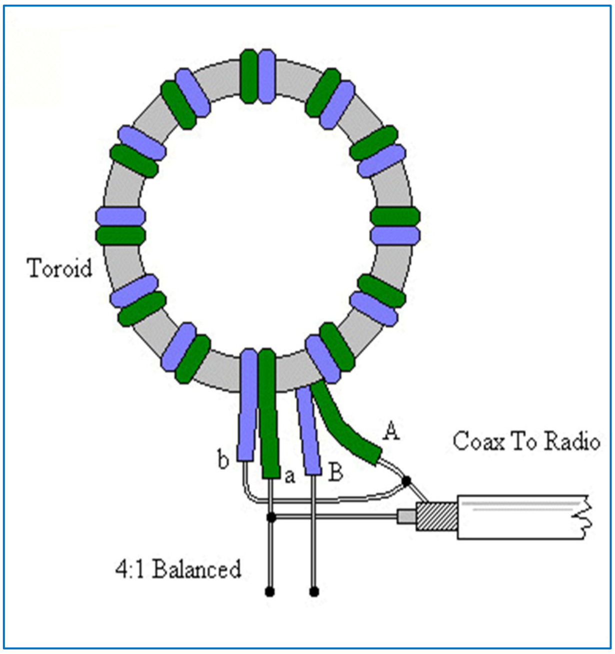

***Figure 3.10***

*Example of 4:1 balun that transforms impedance between the balanced port (200 Ω) and the unbalanced one (50Ω of the coaxial cable), and at the same time short circuits the direct current line.*

In these cases, a transformer *balun* is used at the power supply point, made by means of a double winding on a core in ferromagnetic material, usually of a toroidal shape.

These devices, which generally implement both a symmetrization effect of the antenna currents and an impedance transformation between the radiating element and the feed line, can be made with a layout which short-circuits the inner and outer conductors of the input coax cable.

An example of a 4:1 *balun* is shown in **Figure 3.10**.

In accordance with this design, two conductors of the coaxial line are short-circuited through an inductance wound on the toroidal ferromagnetic core.

This device, is both necessary for antenna operation and offers protection against electrostatic discharges, being an effective solution to avoid electrostatic *charge buildup*.

As regards transient protection (*LEMP*), the inductance of the winding can still have high impedance and so an additional protection consisting of a coaxial surge arrester can be advisable.

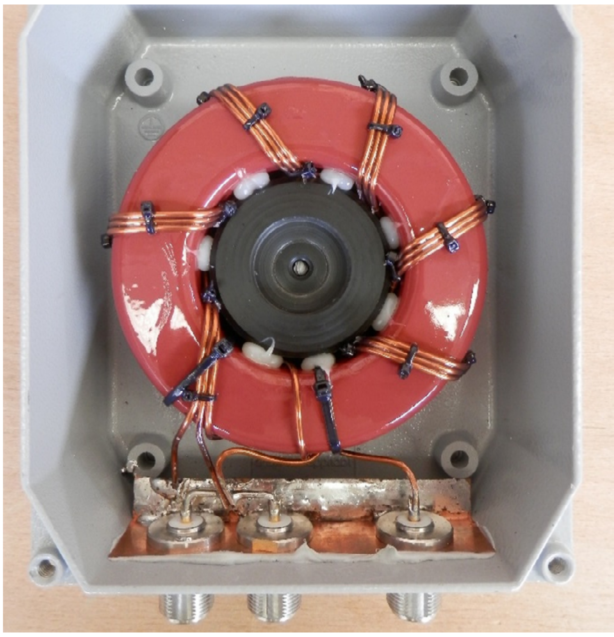

***Figure 3.11***
*Example of a 2:1 unun that transforms impedance between two unbalanced ports from 25Ω to 50Ω.*

Finally, **Figure 3.11** shows an example of the practical implementation of a transformer of this type, wound on a toroidal core: in this case it is an *unun* (with unbalanced inputs and output) designed to couple two antennas in the frequency band from 3 to 30 MHz.

Although in this latter case the device is applied in some point of the antennas feed lines and actually works as a “lumped constants power divider”, it becomes an integral part of the array of two radiating elements which is thus created.

## 5. Conclusions.

After having reviewed, in *PART ONE* of the article, the various types of potentially dangerous atmospheric events for telecommunications systems, in this *PART TWO* the main protection devices that can be both installed outside the antennas or embedded in them have been examined.

Unless we are referring to very large antennas, already designed to handle considerable input power levels (for example in short and medium wave broadcasting), the protection devices incorporated in antennas do not offer guaranteed protection against direct lightning that discharges strong currents towards the ground with destructive results.

In the design of a *custom antenna*, if requested, a protection device is foreseen: this neutralizes the accumulation of electrostatic charges and grounds the radiating elements without compromising the electrical characteristics of the antenna itself.

These “internal” devices are sufficient for most applications, especially if they are adopted together with other “external” protection systems of the structure on which the antenna is mounted, so that the latter does not become the preferential path of the lightning current.

In the event that the radiating elements of an antenna are not physically grounded, it is important to assess the need to envisage a short circuit for the direct current incorporated in the antenna itself on a case-by-case basis. In fact, there may be some specific applications that must necessarily have or not have a "short-circuited" antenna.

In this regard, consider the following two real examples.

- *Short-circuited antenna for direct current.*

Necessary in the case of applications in particular operating environments, subject to electric surges that cannot necessarily be attributable to atmospheric events, such as a TETRA antenna for railway applications, which must be installed on the roof of a railway wagon or locomotive near the pantograph that takes its current from the power line above. In this particular case the antenna system needs to be adequately protected from lightning due to accidental failure of the power line.

- *Open circuit antenna for direct current.*

Antenna connected to an amplifier/preamplifier stage whose output port is not decoupled from the power supply by means of a series capacitor. This can essentially be due to three reasons:

  - need to insert a *phantom* power supply in the antenna cable with consequent risk of short circuit;
  - specific choice, let's even say unorthodox, of apparatus design;
  - presence of other parts, extended and physically grounded, in an antenna which do not make it necessary to insert a short circuit in the power supply line, not directly connected to the radiating element.

The latter cases deserve further study, given that the subject affects the design criteria of an antenna depending on its particular application.

Here we will only say that this aspect too can be relevant and worthy of an in-depth examination when preparing the development of a *made-to-measure antenna*.

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