COHERENTLY RADIATING PERIODIC STRUCTURES (CORPS) AND THE HUMAN EYE: WORKING PRINCIPLE

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ABSTRACT.- In this paper a new philosophy to design antenna systems is presented. It is based on the recently proposed Coherently Radiating Periodic Structures (CORPS). These structures are essentially a periodic structure which all the elements are radiating elements coupled coherently (in-phase).

The working principle of these structures is quite similar that the working principle of the photoreceptors of the human eye detecting images, opening the possibilities to define high resolution artificial visual systems.

1. INTRODUCCIÓN

One of the most important requirements of all the antenna systems is the angular resolution achievable, to be able to distinguish two punctual sources placed quite close to each other in far field. The angular resolution is determined by the possibility of having high directive beams quite close to each other.

With the actual technologies, the antenna systems having one or more high directive beams at microwave and millimetre wave ranges could be classified in two kinds of systems:

a).- systems with a *unique lens* or focusing device, and
b).- systems with *multiple lenses*.

In the first case, the possibility to increase the number of beams passes by admitting some kind of distortion of the beams placed out of focus. Practically all the more commonly used antenna systems are included here, some of them with more focusing capabilities in the lens or focusing device and some others with more directive radiating elements. The classical parabolic reflector antenna with the low directive feeder could be an excellent example of this type of systems, but also the multi-feed reflector antenna configuration.

The HFI and LFI experiments of PLANCK [1] use this configuration of multiple feeds and multiple frequencies illuminating only a unique reflector system, and equally, every one of the radiating elements of ALMA [2] and VLA [3] experiments.

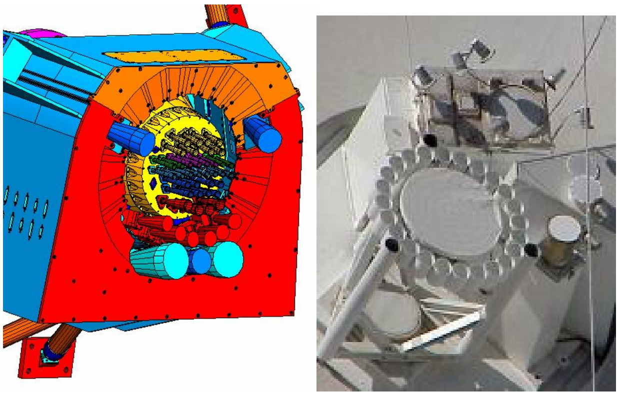

Figure 1.- Multiple feed disposition at the focal plane of the PLANCK (left) and VLA (right) systems.

The second case is the case of the big arrays configurations, where the radiating elements are complete antenna systems disposed over a large area with a special lattice. Examples as ALMA [2], VLA [3], etc, are well known by all the scientific community.

Figure 2.- VLA system picture. Each reflector includes at its focal plane the multiple feed configuration shown in figure 1.

However, as it is very well known, in both cases, the main problem is the angular resolution achievable, since there is no possible to reduce the distance between high directive beams below the aperture dimensions of the radiating elements.

The limitation of having a small number of detectors per lens reduces the possibilities of natural extension of the actual technology to handle a large number of detectors.

In front of that limit, the only valid solution, to enlarge the system, is to iterate the full system itself, obtaining some kind of compound eye of some insects, where there are a lot of small antennas (detectors) focused by its own lens (*ommatidia*), conform a complete visual system.

Of course, due to the size of the different receiving elements (small lenses in the case of the compound eyes of the insects) the angular resolution is equally limited.

Nevertheless, in the nature there are some examples of antenna systems with impressively high resolution. One of the most extended is the human eye that it is working at optical frequency range and the achievable resolution is really impressive.

This paper want to be an invitation to study the working principle of these kind of eyes as detectors, to consider the viability of applications of these principles to the antenna system design at lower frequencies.

1.1. Angular resolution of the Human Eye

The human eyes have an impressive performance. They are able to focus near and far objects automatically; they have possibilities to see under bad circumstances (low light); they are able to control de entrance of light to prevent possible saturation of photoreceptors; and finally, the most impressive feature, the really high resolution of the obtained images.

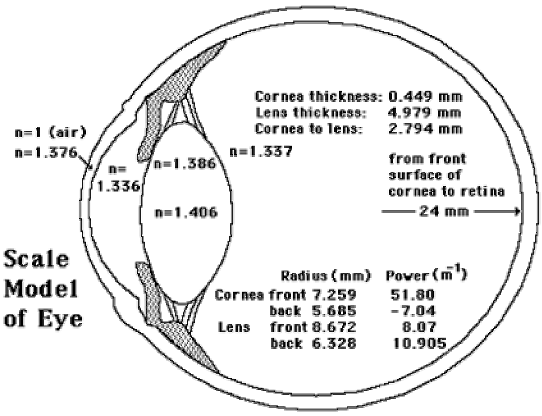

Figure 3.- Scale model of human eye, including its lenses and its refraction indexes.

But, it is even more impressive if we try to understand the human eye under antenna parameters. To be able to distinguish two points quite close to each other at certain distance, we should need some kind of really high directivity.

Some people like to assign to the brain the capabilities to obtain such high resolution images, but it is clear that it could be difficult to “generate” small details that have never been received by the eye. It could be understandable some kind of interpolating post-processing technique to try to solve points placed between photoreceptors to obtain a continuity sensation of the images, but this never would generate additional details in the image increasing the resolution.

Finally, the sensor, the human eye, should be able to provide to the brain as much information as possible, and even, if it is possible, it should be able to include some kind of redundancy in the information in order to increase the robustness of the complete vision system.

In principle, in the human eye, the light passes through the cornea and the crystalline having a focus situated just over the retina. The total refractive power of the human eye is measured in dioptres and it is determined by the inverse of the focal length, being 62 the considered normal value for a current human eye [4]. This means that the focal length is then 16 mm, and it corresponds with the separation between the crystalline and the retina. Then, the images in front of the eyes (just at the focal plane outside the eye) will be inversely projected over the retina as in a photographic camera.

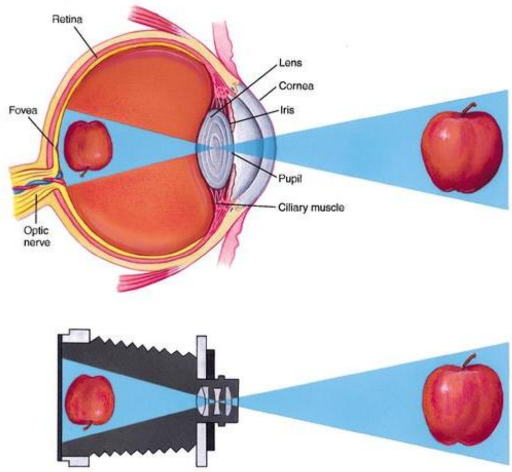

Figure 4.- Optical focusing system of the human eye and a photographic camera, showing the similarities in the inverted projected image over the retina or the film respectively.

Over the retina there are special cells, photoreceptors, specially prepared to receive the information modulated at optical frequencies introducing this information in the neural system to the brain to process.

There are different kinds of photoreceptors: cones and rods. The cones responsible of the coloured vision and the rods more related with the vision under poor lighting conditions.

It is also well known that we really have properly focused a small cone subtended in an angle of less than one degree, and the responsible of this is a small area on the retina just centred at the vision axis called *Macula* recognized as a depression of the retina surface being the deeper point knows as *Fovea*.

In the Macula, the density of cones is 160.000 per square millimetre being the main responsible of the focused central vision. The Macula is in fact acting like a divergence lens, dispersing the parallel rays arriving close to the optical axis over a wider area of receptors. This divergence effect is not included properly in the optical system of the eye since the Fovea is only 100µm deep, and the dispersion effect is really small and only relevant for the increase of area of receptors affected.

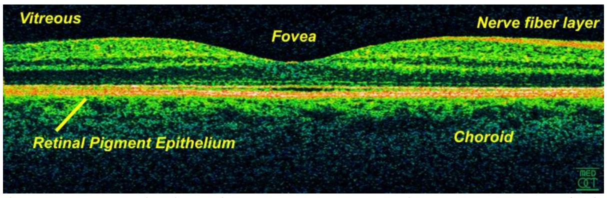

Figure 5.- Optical Coherence Tomography at 800nm of the *Macula* in a human retina.

It is also known that the cones diameter is approximately 1.5µm and the separation between two cones is about 0.5µm.

With these dimensions, if we apply the photography principle and we expect to obtain focused over the retina the inverted image, we could calculate the resolution of the retina image simply translating the separation between two cones outside the eye. To solve two different points outside, the retinal image should have an "unexcited" cone between two other excited ones by the two points respectively, given a distance of 4µm as the minimum distance necessary to solve two points on the retina. Translating this distance out of the eye up to a distance of 350mm (reading distance), these resolution step is 84µm. This is a angular resolution of 50 seconds of arc, in other words, the directivity associate to every cone should be 81dB in order to be able to distinguish the two source points.

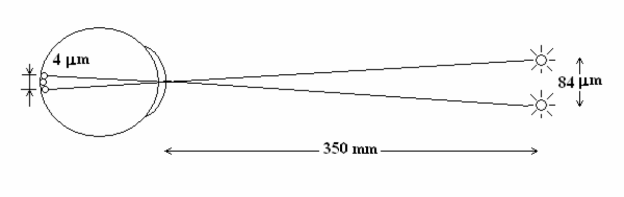

Figure 6.- First approximation of human eye resolution.

Nevertheless, this simplified model is quite difficult to understand if we include the capability to distinguish two coloured sources keeping the resolution features, and the capability to discover objects or details subtended in angles of one second of arc.

1.2. Higher resolution explanation

Some authors suggest that there is a very quick and small oscillation movement of the eyes that could help to refill the empty spaces between cones.

At that point of the explanation it is important to think a little bit about the detection mechanism. The cones are not detecting the carrier signal (optical frequencies); they are really detecting the modulated signal. Certainly, each type of cone has its own frequency response to optical frequencies, being more sensible to different colours: red, green and blue.

In a simplified model, we could think that the cones could be acting as integrators, just counting the number of photons received.

Under the assumption of the rapid and small vibration of the eye to increase the resolution, it could be argued that it could really difficult to think that the brain could know exactly the position of the eye when each photon arrives to each cone to reconstruct the higher resolution image. Assuming this integration behaviour, this vibrating phenomenon could really diffuse the image over the retina.

Furthermore, in the optical theory the light is considered to travel in straight lines, but really some diffraction should be consider since the light is also a wave. This means that really the light will not focus in a single point but in an area. This phenomenon again generates some diffusion of the retina image.

But even more, if we study the chemistry reactions of the reception mechanism of a photon by a cone, some horizontal coupling between neighbouring cones have been reported [4], in some kind of amplifying effect ensuring that all photons are properly received by the retina.

All these three phenomena generate some kind of distortion in the retina image since the information of one photon is effectively spread over some area of the retina, either by the diffraction of light, by the movement of the eye or by the chemistry mechanisms.

So in summary, originally where we were expecting to obtain an image perfectly focused over the retina, since is placed just at the focal plane of the eye lenses (cornea and crystalline), and we are really obtaining a totally de-focused image.

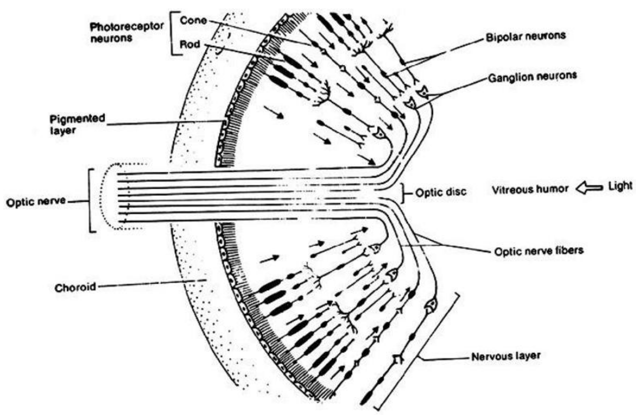

Figure 7.- Representation of the real disposition of neurons and photo-receptors of the human retina.

Looking carefully at the total composition of the retina, we found two additional layers of neurons over the light receptors highly interconnected. These two layers could perform some kind of image processing trying to build a higher resolution image to be sent to the brain through the optical nerve.

This could be possible thanks to the inherent coherence of the eye as a detector of photons. The effect of a photon over the retina finally excites a set of photoreceptor cells, as it was justified above. With the neural networks we could identify without any problem the impact point calculating the position of the maximum.

To do this in only one layer, we should have as much neurons as detecting cells over the retina, being every neurone connected to several retina cells (this number should corresponds with the number of excited cells by a single photon) and applying a threshold function.

Under the inherent coherence conditions of the detection mechanism, the linearity perfectly applies with any distortion phenomena, so by using a single layer of neurons we really could clarify the diffused retinal image, effectively increasing the resolution of the received image.

There are some advantages of having a diffuse image over the retina to be clarified afterwards, but the most important is the robustness of the vision system is substantially improved since the information over the retina is redundant. By this method, it could be understandable that different types of cones and rods could be working together to define the small details of the image in front the eyes.

Coming back to the antenna design theory, it is clear that to obtain a high directive beam, some area over the retina should be effectively used, having highly overlapped radiating areas that could justify very close high directive beams, and therefore, high resolution.

2. DEFINITION OF THE COHERENTLY RADIATING PERIODIC STRUCTURES

In the range of microwaves and millimetre waves, the detecting mechanism of the antenna systems are not naturally coherence like the human eye is, and some additional care should be taking into account to apply the same principle to that lower frequencies.

The CORPS (Coherently Radiating Periodic Structures) will be the kind of antenna systems that uses this mechanism to obtain high resolution at microwave and millimetre wave frequency ranges.

The CORPS are essentially a periodic structure which all the elements, equally shaped and sized, are radiating coherently, and they consists basically on the use in our favour of the mutual coupling always present in most of the antenna arrays.

The key idea is to accept the inevitable presence of the mutual coupling between elements but force it to be coherent (in-phase), as it was naturally in the human eye, controlling the coupling mechanism.

For instance, working with patches over thick substrate as array elements, the coupling could be adjusted to be in-phase (coherently coupled) by separating them an effective wavelength of the substrate wave-mode.

At the same time, by doing this adjustment to have the mutual coupling in phase, the periodic structure formed by the elements is tuned at the second rejecting band of the filter, since the lattice is a full wavelength, so no propagation is allowed horizontally through the substrate. Then, only the elements surrounding the active one (fed) will couple some power by reactive coupling (Fig. 8), increasing the radiating effective area of each individual element of the structure.

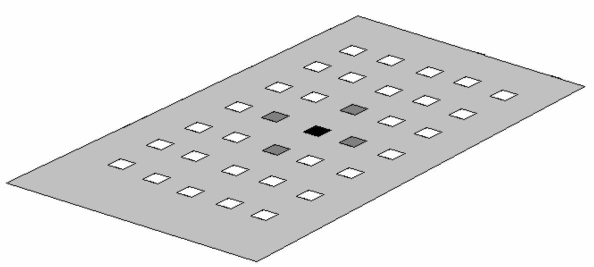

Figure 8.- Coupled elements (grey) when the central element (black) is being fed.

It is obvious that since the basis of all this proposal passes by controlling the mutual coupling between the elements of an array, the design procedure of these structures wont be an easy task. There is still al lot of research to be done in this field to complete define properly a Coherently Radiating Periodic Structure, but if sometime we are able to define such structure, we will have an antenna system with an angular resolution unthinkable since then.

3. CONCLUSIONS

In this paper, the new concept of the CORPS has been presented. It is inspired in the human eye model and opens many opportunities to enhance the resolution in many antenna systems.

It is important to notice the importance of the diffused and coherence mechanism of detection of the rods and cones, since this is the basis of the proposed Coherently Radiating Periodic Structures.

4. REFERENCES

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