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EMC Revisited: A new perspective on safety assurance using smart networks

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Abstract

The increasing use of RF (Radio Frequency) technology (in particular mobile phones,) as well as a tendency towards device designers using the lowest logic levels possible has raised many issues with Electromagnetic Compatibility (EMC) over the years. These issues can have wide ranging effects, up to and including the loss of human life. This paper briefly presents the history of EMC issues and proposes a system for monitoring the levels of activity within a defined space, both with respect to their effects on human life and their effects on other equipment. The proposed system is particularly relevant to high risk areas such as hospitals.

Keywords: Smart sensors, beamforming, electromagnetic compatibility, immunity, functional safety

1 Introduction

Consumer worries about electromagnetic fields have been present for many years, originating with worries about the effects of the electric oven on food in the late 1800's, and returning in strength in the 50's with the introduction of the microwave oven. It wasn't until the late 1960's that scientific research began in the area [1] while the first study into the correlation between exposure (at power frequency) and childhood leukemia was published in 1979 by Nancy Wertheimer [2]. A much more recent example, perhaps showing the strength of public feeling (and the misinterpretation of scientific information by the media) in relation to this topic is the proposed 400kV power backbone from Whakamaru to Otahuhu [3]. A main issue in this case is the possible effects of these power lines on the health of the people and livestock living nearby.

A (typically) more trivial problem with electromagnetic fields in the modern day is their tendency to interfere with each other. The concept of radio licensing was introduced in the early 1900's, [4] with perhaps the first paper [5] on EMC as we know it today being produced in 1932 dealing with interference between automobile ignition systems and radios in the US Military. This problem becomes much more critical when it effects equipment that people depend upon for their lives.

Due to both the issue of health and interference, Electromagnetic Field (EMF) measurement is becoming increasingly important. It is to this end that we propose the development of a system that can be incorporated in sensitive areas for keeping track of adverse power levels and giving feedback on their location.

2 Health Effects

Biological effects of electromagnetic fields are typically subdivided into two categories: thermal and non-thermal. Thermal effects are proven, and are based on the amount of energy imparted by the field on a human cell. This energy appears in the form of heat, and is the principle that the microwave oven works on. These effects are mostly related to acute exposure.

Non thermal effects are much more controversial – they are related to chronic exposure, and are therefore harder to quantify. While there have been studies showing correlation between various types of cancer or skin disorder (such as [2]) these studies often lack repeatability, and for every one showing correlation there is another showing none. An excellent summary of the available studies can be found in [6] and [7].

The consensus of the reviews mentioned above is that while there is no conclusive evidence towards either side of the argument, precautions should be taken to minimize exposure levels, and further research should be conducted.

3 Equipment Effects

A massive increase in consumer use of wireless devices including Bluetooth, 802.11 and mobile phones in particular has lead to an increase in the chances of devices interfering. This interference can be fairly innocuous, as in the form of two wireless networks interfering and resulting in lower data rates, however sometimes the danger is much greater. This is particularly the case in hospitals and aircraft, where the field generated by a typical mobile phone can cause problems with sensitive equipment [8]. A standard mobile phone may transmit around 0.8W in low power mode, which gives a 3V/m field (a typical required immunity level) at around 2m [9] (dependent on the presence of reflecting surfaces.) A mobile phone inadvertently placed on top of a piece of sensitive equipment, or in the pocket of someone standing nearby would obviously generate a much stronger field, and therein lies the problem. Between 1979 and 1993, the US Food and Drug Administration (FDA) received reports of 91 cases of equipment malfunction attributed to EMC issues, which resulted in 6 deaths [10]. It is important to note that these issues are likely to be grossly understated due to a lack of understanding relating to the effects of Electromagnetic Interference (EMI.) Current numbers are also likely to be higher due to increased use of wireless technologies as mentioned above.

One mitigating factor that we have in new technologies is the increasing use of Spread Spectrum (SS) technologies, which have very low Power Spectrum Densities and thus tend to cause fewer immunity issues. We have also seen a slow fade in the use of handheld radios operating in the VHF (Very High Frequency, 30MHz-300MHz) range, which could transmit with powers in the range of several watts.

4 Current Measurement Methods

The current market provides several options for the measurement of EMF's. They consist in general of:

- Cheap handheld single or dual band systems with poor accuracy and little tunability. These will often be at either power frequency or microwave oven frequency (2.45GHz) – the two main points of concern in consumer knowledge.
- More expensive handheld calibrated systems, often used by more professional EMC testers, or those with some knowledge in the field.
- Use of a spectrum analyzer or EMC analyzer and calibrated antenna.

All of these options require extensive user input – they may be useful for detecting permanent sources of interference, but will not be continuously in use. In this situation transient signals such a mobile phones will not be detected. Our system is designed to provide a new option. It will not necessarily provide precise measurement of fields, but instead will provide a continuous Pass-or-Fail test of EMF conditions within a room.

5 The Proposed System

5.1 A Smart Network

The system proposed will utilize several sensors permanently mounted around the location, and use beamforming to "sweep" the area, providing continuous coverage and measurement. Due to the use of scanning, it will also be able to provide some indication of the location of the offending object. The suggestion is that this system may either be implemented in the construction of new buildings (particularly hospitals) or retrofitted to those currently in use.

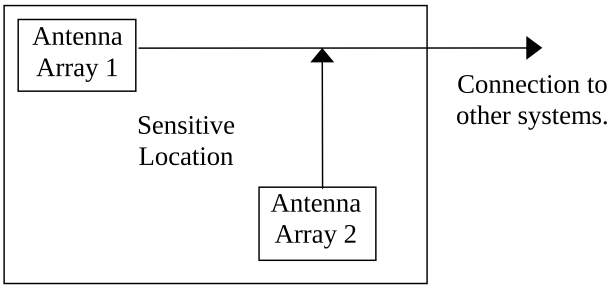

Figure 1: System Overview

The completed system would consist of one or two sensors per room connected to a central computer (in the case of a built in installation – see Figure 1) or self contained units – see Figure 2. In the case of the self contained units, they would contain in essence:

- An antenna array,
- a RF circuit to tune the system and reduce it to a suitable frequency level through heterodyning,
- a method of achieving variable phase shifts between the antennas,
- either a Digital Signal Processor (DSP) or a microcontroller to provide the processing power,
- a power source,
- a warning system, perhaps in the form of an audible alarm.

The system will then not require active monitoring.

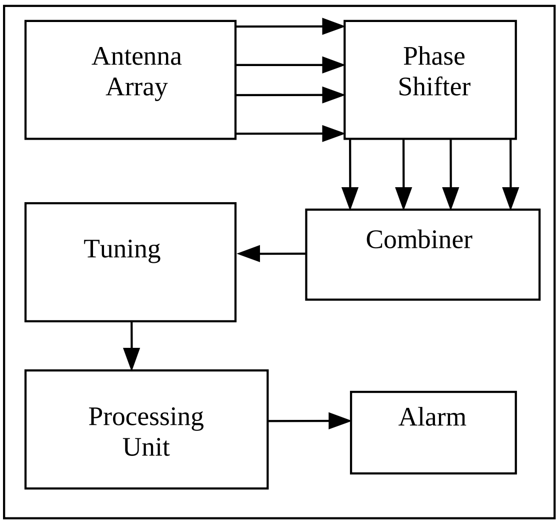

Figure 2: Block diagram of a self contained sensor.

5.2 Beamforming

A beamformer (also commonly known as a phased or driven array) consists of multiple antennas placed in a set pattern. The antennas have a phase shift network between them, which allows alteration of the combined radiation pattern.

A simple beamforming array can be implemented using a Uniform Linear Array (ULA) of 4 antennas with spacing of $\lambda/2$ as shown in Figure 1. As a receiving antenna we consider the array to sample the signal in the spatial domain. Note that a ULA has no ability to discern which side of the array a signal comes from. This ambiguity can be remedied through the use of 2D arrays.

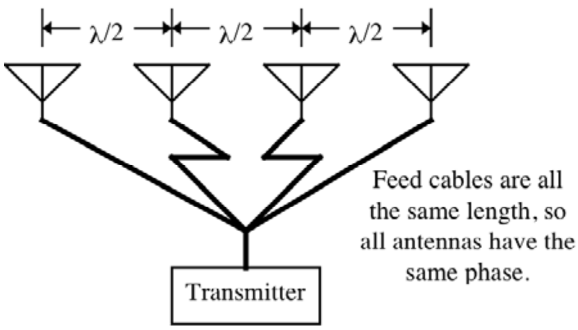

Figure 3: Four Element 1.5λ ULA [11]

Assuming we are in the far field, if the signal arrives perpendicular to the array each antenna will receive the same signal at the same time (as path length is the same.) When the signals are added, they create constructive and achieve maximum gain, as shown in Figure 2.

If the signal comes from end on to the array (0° or 180° in Figure 2,) samples will be $\lambda/2$ out of phase with each other, and thus will cancel completely, making a null at these points. The antenna has now formed two beams.

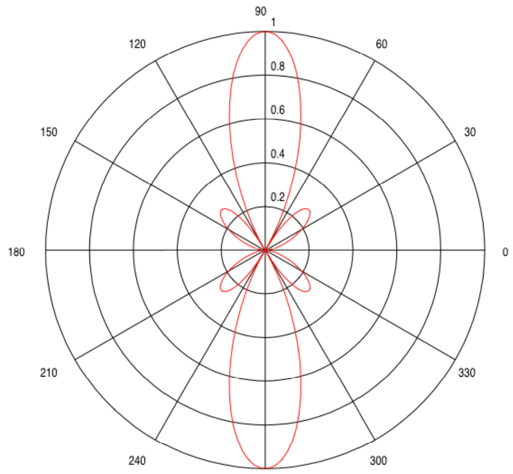

Figure 4: Radiation pattern for a horizontally oriented Uniform Linear Array. [11]

It is possible to "steer" the beams by applying a phase shift to each of the received signals, thus effecting how they are combined. Applying a complex weighting to the signals allows very fine control of the locations of beams and nulls.

It can be shown that the Direction of Arrival (DOA) of a signal is related to its frequency as well as the properties of the sensor:

$$\theta = \cos^{-1}\left(\frac{\Delta\varphi\lambda}{2\pi d}\right) \tag{1}$$

Where θ is the DOA, Δ• is the phase shift imparted by the phase shift network, • is the wavelength of the signal and d is the distance between array elements.

The spacing of the elements and length of the array will affect the performance of the antenna, as would be expected through Fourier theorem. As such the length of the array (corresponding to the length of the sampling period) will determine the beam width, with a longer array generating a tighter beam. The density of the array corresponds to our sampling rate, and thus is governed by Nyquist. If we sample below Nyquist, we will introduce aliasing (referred to as "grating lobes" in this situation.)

5.2 Use of beamforming in a smart EMF network

By combining incoming signals with a varying phase shift, we can generate the effect of scanning the room. The fact that the direction of the beam is frequency dependent can be combated in two ways:

- Use of several narrow band scans, limiting the variance in direction. These bands could be specifically targeted – for example at the uplink frequency band for GSM mobile networks.

- Use of a more complex system for distance estimation. This would require first estimating the frequency of the received signal, then using this information to find where the beam was pointed.

By using either of these methods we are able to profoundly refine the measurement capability of a single sensor. It is predicted that either one or two sensors would be able to cover an entire room.

The use of several narrow band scans is of course far more pertinent, as it allows the use of a narrow band receiver. In the single scan method heterodyning the signal to a suitable level for A/D conversion would become nearly impossible, and we would instead require an ADC with an extraordinary sample rate to allow proper signal reconstruction.

At 900MHz critical spacing of an array is found to be around 16cm, meaning an array of four antennas would have to be around 64cm long. We can reduce our spacing to around $\lambda/4$ while still maintaining a relevant beam in this situation, which would give us a sensor approximately 32cm in length – a much more reasonable proposition. Due to this length requirement, the system would not be particularly suited to reception below the UHF (Ultra High Frequency, 300MHz-1GHz) band, missing in particular the VHF band as typically used in handheld radios. Non directional reception in these areas could be implemented, though this would not allow distance mapping with any level of accuracy. In areas where transmission in these frequencies was expected to be a problem, the system could be supplemented with several single antennas throughout the room.

5.3 Distance Mapping

Once the sensor is installed in a room, a map can be programmed into the device so that it can determine the signal power using the approximation:

$$P \propto \left(\frac{\lambda}{4\pi d}\right)^2 \qquad (2)$$

Where d is the distance to the source, λ is the wavelength of the signal and P is the received power. This needs to be adjusted for the directivity of the array. Also affecting the received power is constructive and destructive interference, provided by reflections. This needs to be taken into account when choosing power limits.

The mapping provides perhaps the greatest source of error in our system, however provided we make conservative estimates it is likely this will not pose too much of a problem. It was revealed in field measurements that mobile phones and similar generate fields at least an order of magnitude greater than the standard noise floor, which for comparison lies at around 100μV/m in a busy computer lab at the 900MHz range. This allows us a significant margin of error.

The distance map can be created using simple trigonometry, dependent on the size and regularity of the room. It is probable that in most cases a suitable approximation of the map could be generated by assuming the sensor is located in the corner of a rectangular room.

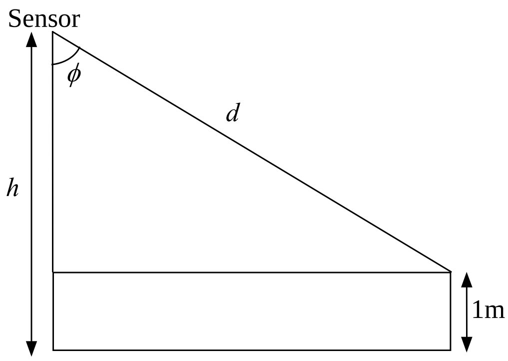

Figure 5: Representation of distance estimation technique.

With just information about the height of the sensor h, we can determine an approximate distance to the source d by assuming a source height around waist level (1m) and taking the vertical angle ϕ at which the beamformer is pointed (with vertically downwards equal to 0°) as:

$$d = \frac{(h-1)}{\cos(\phi)} \qquad (3)$$

This would require the setup of angular limits on where the beam could scan so as not to spend time scanning walls or similar.

5.4 Phase Shifting

Phase shift of the signals would be most simply achieved through use of a programmable electronic phase shift network. This would provide a defined phase shift between each antenna. When coupled with a power combiner, it will mean that the chosen processor has only one signal to sample.

Another option for constructing our beamformer is to have a processor capable of sampling each of our antennas at a speed sufficient to satisfy Nyquist, as well as not adding its own phase shift due to time delays between samples. Each of these samples is then stored into an array. Once sufficient samples have been accumulated, the arrays can then be shifted with respect to each other and summed to provide apparent phase shift. This shift and combine can be altered to provide the requisite scanning. This is possible as we are not dealing with a real time system – in fact, as the system is not able to take any action other than alerting its users, a delay on the order of seconds is perfectly feasible.

6 Conclusions

While health effects of low intensity RF fields have yet to be proven, their effects on precision electronic equipment have been shown many times. Due to these interference issues, a system has been proposed to monitor emissions in critical situations. In this paper we have investigated the possible design issues of the proposed system in a safety assurance role. The proposed system could be implemented in conditions where high fields may be experienced under extenuating circumstances – such as RF engineering. While it would require tuning to the situation, this could be relatively simple with the proper interface software. As the benefits of this system could be the saving of lives, the tuning is considered warranted.

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