Effects of Pulsed RF Disturbances on Aeronautical Communication Systems

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***Abstract*— Air Traffic Control (ATC) and their responsible authorities have been always very sensitive to safety of the systems they are using to guarantee a fool-proof and environmentally safe operation of the facilities to provide guidance for the airplanes. This paper deals with the influence of a pulsed systems on standard air-ground aviation communication systems. A measurement campaign is described. An analysis of the inaccuracies of those measurements is performed and the influence of (shielded and unshielded) spark plug systems on aviation communication systems (still based on A(mplitude)M(odulation)) is explained in detail**

***Index Terms*—pulsed RF, EMC, communication.**

I. Introduction

Safety of ATC equipment does not only implies that its ruggedized construction can withstand severe operating conditions, but also that people/engines in the neighbourhood cannot either influence the working of the systems or be influenced by them. This paper will limit itself to the effects of unwanted radiation from pulsed sources like ignition engines on communication systems.

II. Effects on Communication Systems

The main concern of the authorities was the construction of a nearby (about 55 m) road, close to the reception centre, where the communications of the pilots are received on the ground. The receiving elements are vertically polarised and mostly linear antennas (with two exceptions for the communications towards planes coming from France) mounted on four 20 m high towers (Fig. 1). Class A equipments, according to the CISPR 22 (Comité International Spécial sur la Protection Radio-éléctrique) standard [1], are allowed to generate spurious electric fields of 57 dBμV/m for the electric field at a distance of 3 meter from the noise source or 47 dBμV/m for normal equipments at frequencies above 250 MHz and 50 resp. 40 dBμV/m in the band from 30-250 MHz. They correspond with linear field strengths of 708 μV/m and 316 μV/m for class A above 250 MHz and 224 μV/m below as well as 100 μV/m for ordinary equipment (|E|=10dB/20 μV/m).

Fig. 1: Reception centre for air to ground communications.

Based on the EPICS program [2], it is very easy to compute the fields below the receiving antennas, needed to obtain a given voltage value in the receiver (Fig. 2). It was found that theoretical computations implied that a safe distance of 495 m had to be kept for all class A interferers. It was first verified experimentally on 25-2-2000 that most cars (in this case a Pontiac Transsport model 1993 with a plastic frame, where all electromagnetic waves can travel trough nearly unimpeded) were complying with those standards. On 29-2-2000, a Chrysler neon was tested in even worse circumstances: a spark plug was removed from its cylinder so that the spark was visible. Even then the values remained within the CISPR 22 limits, but coming very close (Fig. 3).

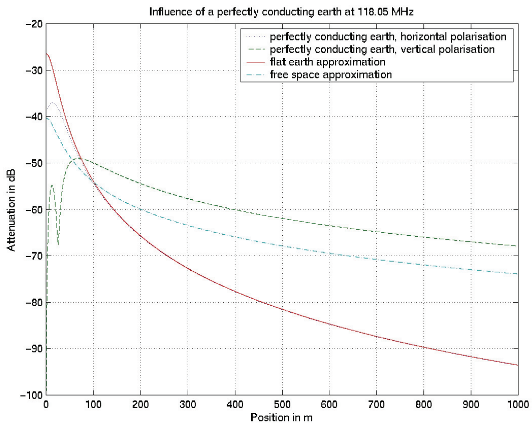

Fig. 2: Loss computations for both polarisations above a perfectly conducting ground, including approximated free space formulas.

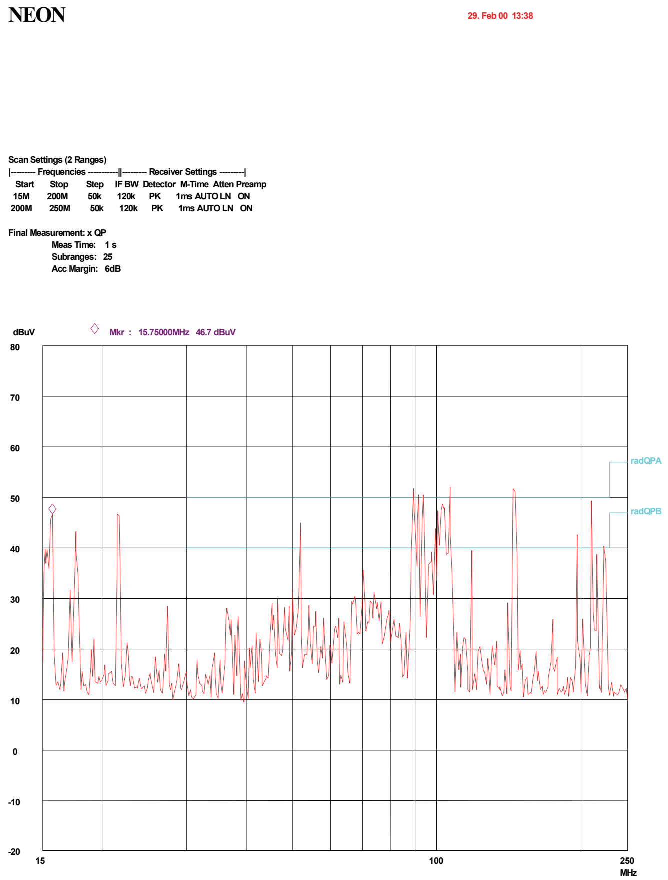

Fig. 3: Spectrum of a car, measured in the open area test site of the De Nayer Institute at 1 m distance.

However, the actual road, passing by at 275 m, never caused any interference problems (the only problems they ever experienced was a grass cutter, but close to an auxiliary antenna, located on the roof of the building and not on the tower, as well as a bad vacuum cleaner, used in the rooms where the receivers were located). Measurements performed by the CCRM (Centre de Contrôle des Radiocommunications des services Mobiles, a non-profit private certification company) also indicated that they were able to induce interference at a distance of 400 m from the receiver with a continuous signal. This has forced us to analyse more in detail the behaviour of the receivers in the presence of pulsed signals. The analysis of a spark plug signal in a classic ignition system with transformer coils used both as an inductance and to generate the high voltage is very interesting. Indeed, that signal consists in a series of short sparks, every time the damped oscillation voltage is exceeding the breakdown voltage. We noticed that for every opening of the contacts about 7 sparks (random between 5 and 9), one about every 180 nsec. were generated, one every time that the voltage over the inductor was sufficiently high to initiate a voltage breakdown (Fig. 4, P(ulse)R(epetition)F(requency) about 182 Hz). The pulses themselves are extremely small (about 50 nsec. in duration,), leading to a worst case duty cycle of 50/180 or 27%, leading to an absolute worst case distance reduction to 138 m. For a 4-takt engine, the maximal PRF is 500 Hz, if we assume that the maximal number of R(evolutions)P(er)M(inute) is 15000 (1 spark/2 revolutions x 4 cylinders= 2 spark pulses per revolution of the engine axis). If we use this maximal PRF of 500 Hz (2 msec.) and the largest number of observed sparks (9), this is distance is further reduced to 111 m.

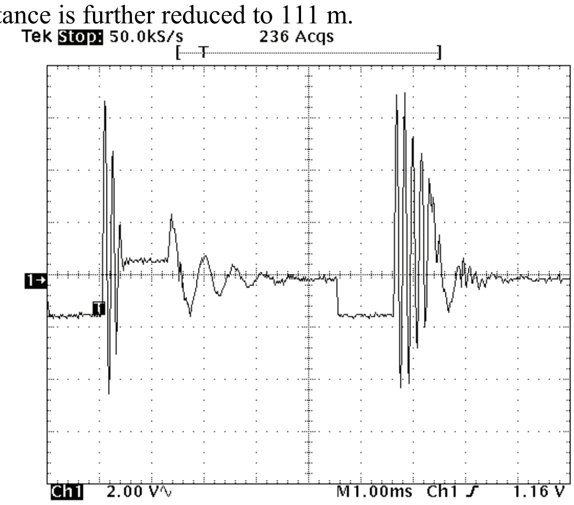

Fig. 4: View of the signal on the primary of the coil.

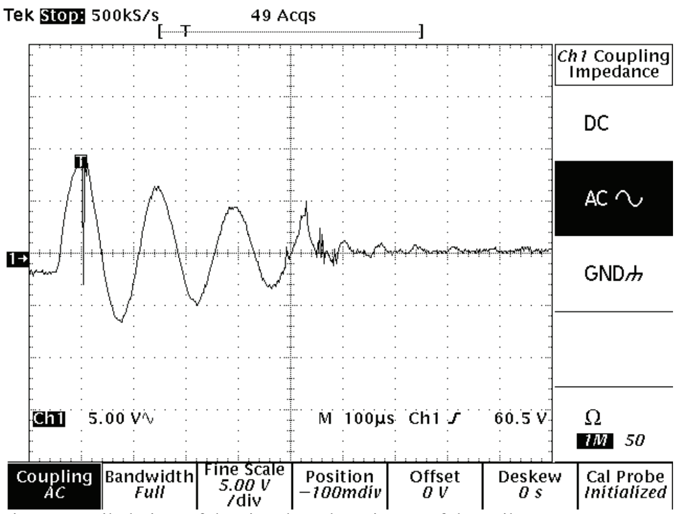

Fig. 5: Detailed view of the signal on the primary of the coil.

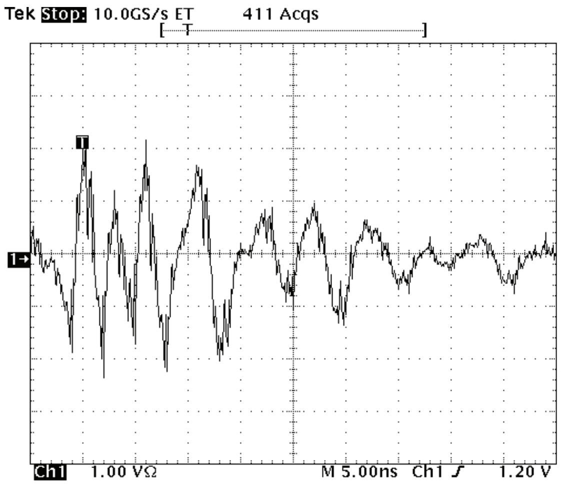

Fig. 6: Detailed view of the signal within a spark measured on the output port of a wideband antenna.

We expect them to obey the behaviour as predicted by Trichel [3]. This implies that the shape should follow an exponential law like:

$$i(t) = Ate^{-t/\tau} = A\tau(t/\tau e^{-t/\tau}) \qquad (1)$$

where the time constant is of the order of 28 nsec. This should look like Fig. 7.

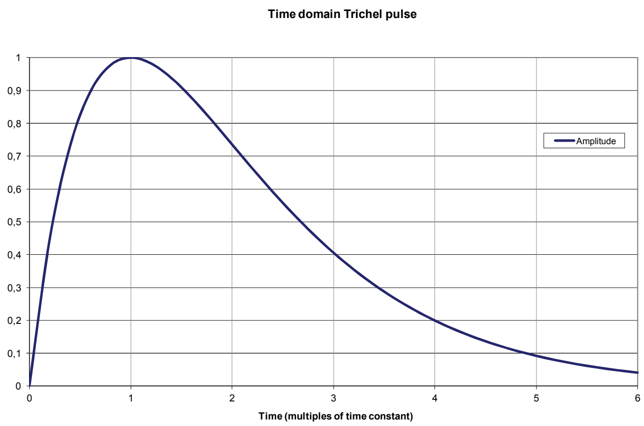

Fig. 7: Shape of an ideal Trichel pulse.

The spectrum can be analytically calculated as:

$$I(\omega)= \int_{0}^{+\infty} i(t)e^{-j\omega t}dt = A/(1/\tau + j\omega)^2 \qquad (2)$$

The discrepancy with the measurement of Fig. 6 is partly due to the fact that the antenna does not couple DC, but gives the derivative of the input pulse. Even then, only one oscillation is expected. This might be due to the fact that many sparks occur nearly simultaneously on the plug (which is a small parallel plate).

To verify our conclusions experimentally, we went around on site first with a calibrated pulse generator from Rohde and Schwarz and a linearly polarised antenna (Fig. 8). This was generating -40 dBm with a duty cycle of 50% and a PRF of 500 Hz at 126.375 MHz. The receivers were set to open at signal of 1 μV, corresponding with -107 dBm. During those measurements, we also noticed that the fence around the path to the receiving centre was depolarising the fields significantly. A DGPS system was used to determine the distance to the antennas (the differential part is the white ball antenna on top of the car; Fig. 9). Then, we used the spark plug commanded by a drilling machine (Fig. 10; of course in permanent contact with military and civilian ATC and the BIPT (Belgian spectral regulatory agency) to stop the experiment within 1 second). We were able to generate interferences up to a distance of 75 m from the antenna towers, while at 120 m no effects were noticed any more.

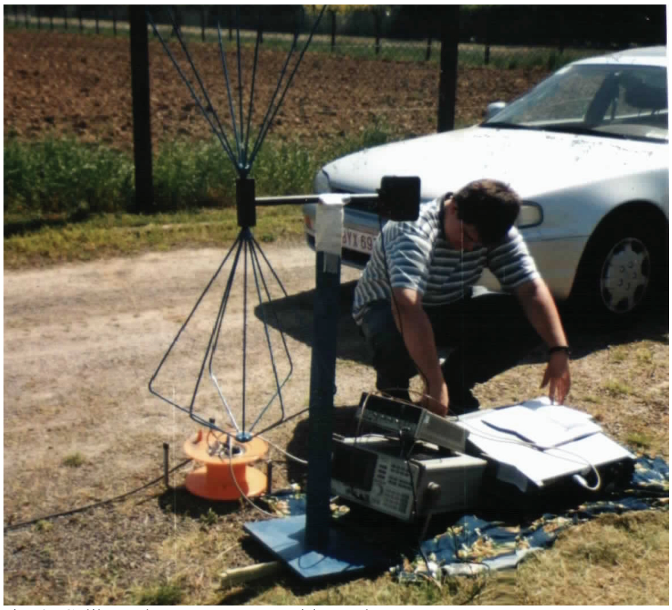

Fig. 8: Calibrated antenna set-up with a pulse generator.

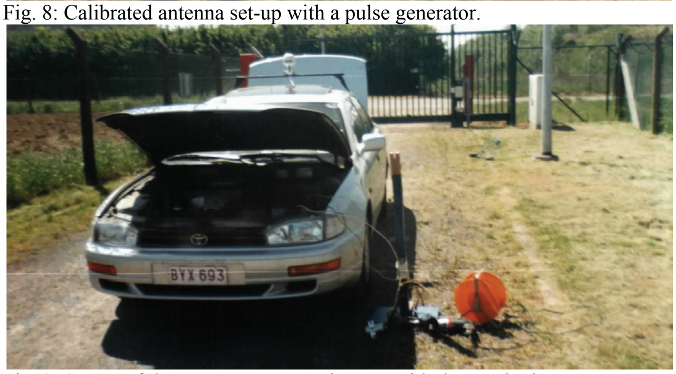

Fig. 9: Set-up of the measurement equipment with the spark plug.

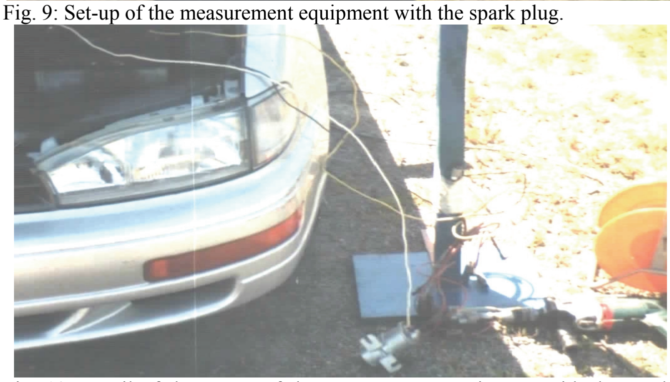

Fig. 10: Detail of the set-up of the measurement equipment with the spark plug.

Let us now look at the spectrum of the spark (Fig. 11). This was measured in an EMC room at a distance of 3 m for the worst antenna polarisation (in this case horizontal) and for a rotation speed of the drilling machine at 2700 RPM. The spectrum is only decreasing slightly (about 10 dB) after 100 MHz, while the spectrum of an ideal Trichel pulse decays at a rate of 40 dB/decade. The spectrum at 400 RPM is, as expected about 8,3 dB lower (400/2700). The rapid variations are due to the measurement time of the system. In some cases not as many sparks are integrated into the measurement. One should essentially look at the envelope of the signal. This disappears at higher speeds. The spectrum of the drilling machine itself (this one was satisfying the EMC requirements) is much lower.

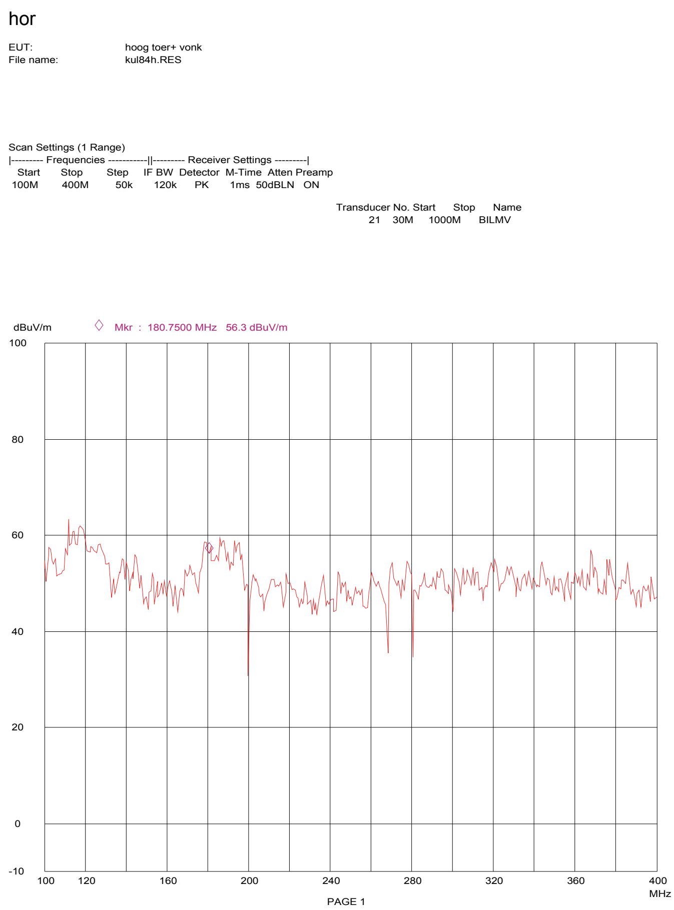

Fig. 11: Spectrum of the spark plug at 2700 RPM (horizontally polarised antenna).

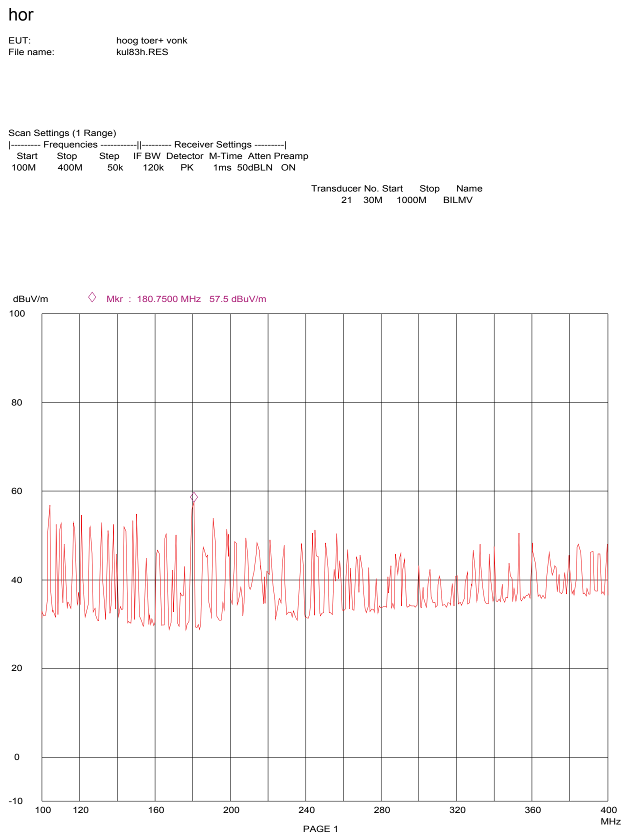

Fig. 12: Spectrum of the spark plug at 400 RPM (horizontally polarised antenna).

We were able to prove experimentally that the effect of a signal, due to the A(utomatic)G(ain)C(ontrol) of the receiver, was, due to an RC filter integration, proportional to the product of the field strength and the duty cycle (Fig. 13). So, a signal with a duty cycle of 5% must be 20 times larger in amplitude or 400 times larger in power than an equivalent C(ontinuous)W(ave) signal before it has a significant effect on the receiver (a small background noise equal to the P(ulse)R(epetition)F(requency) of the pulsed signal may be audible, but usually it is less than the cockpit background noise in the airplane).

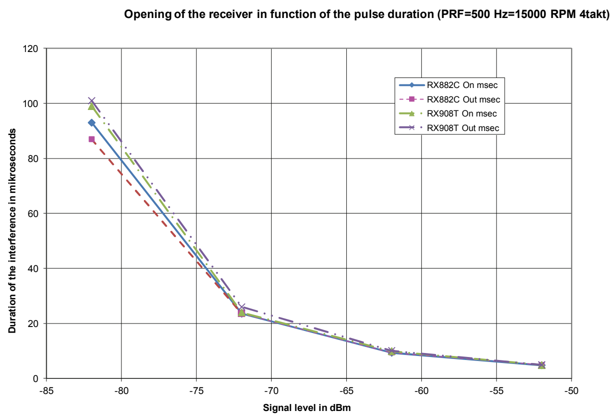

Fig. 13: Reaction of two types of receivers to a signal with a PRF of 500 Hz.

Further computations show that it would be possible to shield the lower (ground) environment from the receiving antennas, while not degrading the signals received from the airplanes by adding a fence on the antenna platforms. A 6 dB shielding would guarantee a fully safe operation at the planned road distance of 55 m. A small 24° inclined screen with meshes of 10x10 cm and a size of 1.36 m would attenuate 6 dB. A 9 dB shielding would even protect the antennas from all unintentional interferences on the ground independently of their distance to the antenna tower (Fig. 14). This could be realised with an inclined mesh of 1.66 m (using the ITU formulas [4]). We also measured the effects of a 802.11b 2 Mb/s frequency hopping based wireless LAN, and a spark generator from a central heating system. The first had no measurable effect at all, and the second had a much smaller effect than the raw car spark system. Since it was not sure that the structure would be able to support this extra shield under all (wind) condition, it was decided to obtain the 6 dB by increasing the sensitivity to 2 µV, also reducing the burden of communications with far away (and difficultly audible) aircraft.

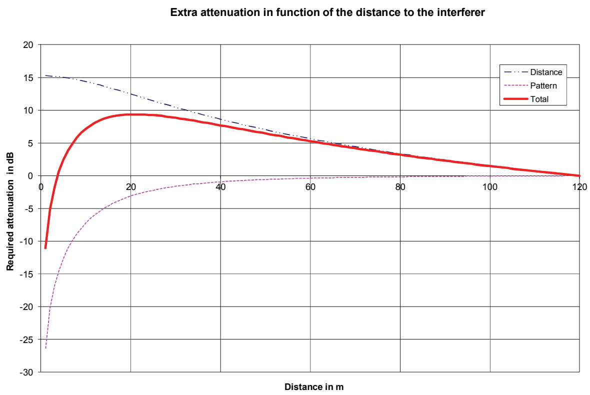

Fig. 14: Extra attenuation required to shield a spark, taking into account the antenna patterns..

III. Conclusions

The adverse effects of badly are usually very limited in space. For communication systems, even if the interference zone remains small (75 m), it would be even possible to design a shield that would completely block interferences from all occasional interferers below the antenna (of course not of intentional jamming).

Acknowledgment

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References

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