Wireless Communications In Vehicles

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Introduction

Whilst driverless cars and vehicle-to-vehicles communications have been grabbing the headlines recently, a quiet revolution has been going on in the field of communications within in the vehicle itself. The smart-phone generation demand constant access to media, and when in their vehicles this is no different. So called infotainment systems are now commonplace in high-spec modern cars, as well as sophisticated sensor networks to control environmental conditions such as temperature and CO_2 levels.

With vehicles already creaking under the weight of hundreds of metres of cabling, wireless communications are becoming an increasingly attractive prospect for manufacturers, not to mention having desired property of allowing users to wirelessly connect their smart devices such as tablet computers and phones to the vehicle's systems. But there is a problem- a good analogy can be made between the radio propagation in a vehicle cavity, and that of a reverberation chamber- a controlled environment designed specifically to make the electric field (and hence wireless communications) as random as possible. How can we deploy effective wireless communication systems in such a harsh radio propagation environment?

We assert that the best way to solve this problem is through a bottom up approach- starting with a rigorous analysis of the propagation of electromagnetic waves in the vehicle cavity, then calculating the theoretical information capacity of the in-vehicle channel, and finally using this to deploy communications systems. Figure 1 shows a test vehicle; figure 4 shows an example deployment using horn antennas.

Electromagnetic Wave Propagation

We can separate the electromagnetic wave propagation into two components: an instantaneous impulse response, and the Doppler spread caused by the random motion of the cavity occupants. Together these two quantities fully describe the propagation.

In reverberation chambers the average energy, *<E>*, decays exponentially with time, *t*, after an impulse:

$$< E > = ke^{-t/\tau},$$

where *k* is a constant and τ is the time constant. We observe this is also a good model for the impulse response of the vehicle cavity, as shown in figure 2.

Regarding the Doppler spread, for our purposes it is sufficient to observe the maximum frequency, f_d, at which a Doppler shift occurs (i.e., before the shifted signal becomes indistinguishable from noise). This is shown in figure 3, and has a value of approximately 40Hz.

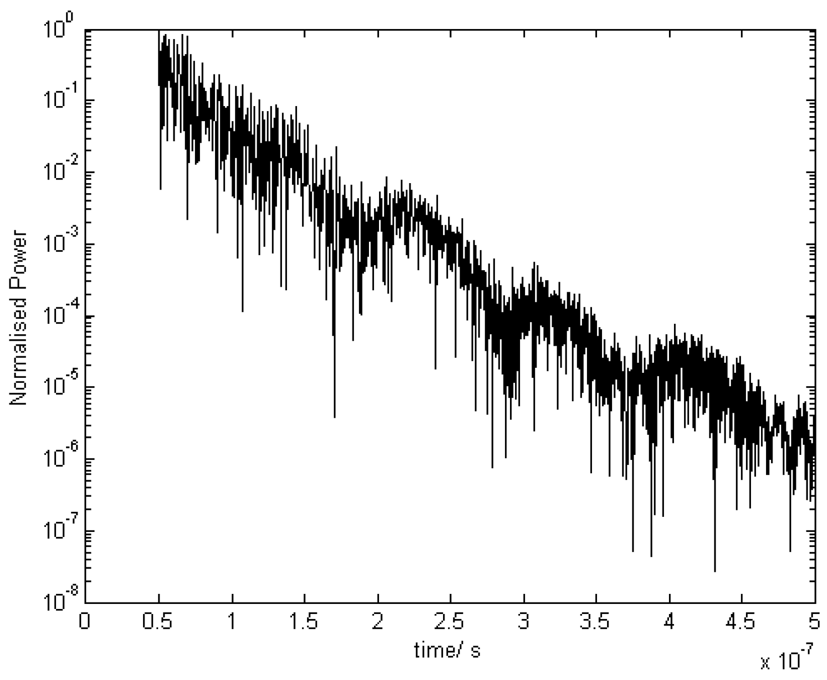

Figure 2: Impulse Response.

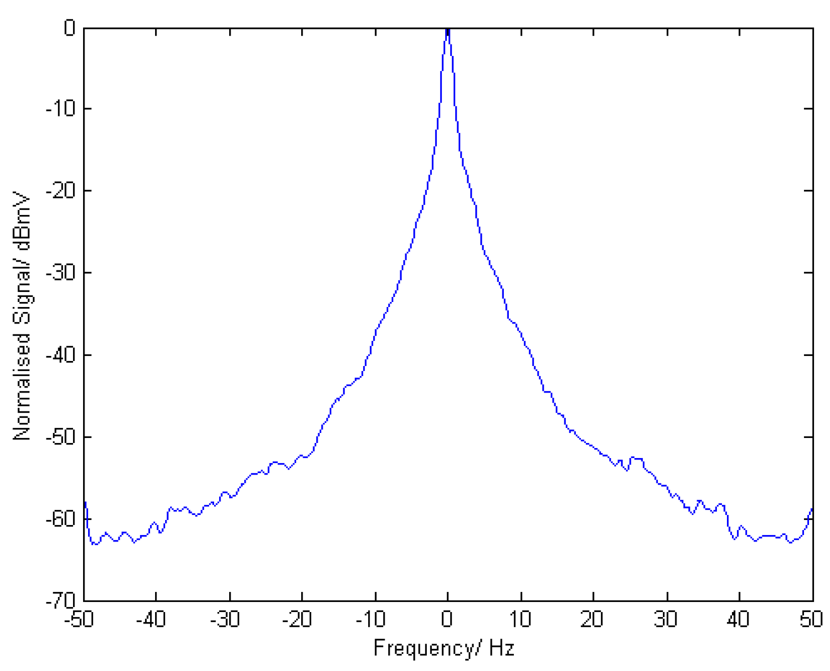

Figure 3: Doppler Spread.

Figure 1: Test Vehicle.

Information Capacity of the In-Vehicle Channel

Conventional wisdom states that if the coherence time (equal to $1/f_d$) is much greater than the time constant, τ, then the channel is underspread and its capacity will be approximately that of the additive white Gaussian noise (AWGN) channel:

$$C = E(\log(1 + |h|^2 SNR))\ bits\ s^{-1} Hz^{-1},$$

where *C* is the capacity, *E(.)* is expectation, *log(.)* is the logarithm to the base 2, *h* is the channel response and *SNR* is the signal to noise ratio. In contrast to the slightly vague wording of the existing underspread approximation, we can show a condition on the product $\tau \times f_d$ sufficient to apply the underspread approximation to a given tolerance (say 99% of the AWGN capacity).

Figure 4: Typical Antenna Deployment.

Effective Communications

To use our insights regarding the propagation channel and information capacity to deploy effective communication systems, we must address three further areas:

1. Channel estimation- i.e., of the parameters τ, f_d and *h*.
2. Channel coding to approach capacity.
3. Resource allocation (i.e., spectrum and time) to the links.

If done correctly this will allow us to deploy an effective communication system for any application. Remaining challenges will be concerned with integrating many different systems in one cavity, sharing the same spectrum.

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