White Paper

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Factors affecting the attenuation of Radio Waves in a real world fire environment

Why Radio Communications Fail in Fire

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Abstract

This white paper brings together research from around the globe to explain the reasons for the failure of radio communication systems in fire, and examines the causes in simple terms, allowing this critical research to be understood by a wider audience.

Introduction

There have been many reported incidences of radio communications being affected by buildings in fire conditions (most recently at the Grenfell Tower Inquiry) but this is not a new phenomenon, and was the main reason for the NFPA adopting fire telephones as part of their building codes (now known as NFPA 72(1)) for buildings over four stories. This has been in place since the late 1970s as residential high-rise building expansion took place in America.

Many of the recent large fires have been in China(note 1)pre Grenfell, and that is the reason they have put so much research into this, the document "A review on research of fire dynamics in high-rise buildings"(2) cites 87 associated papers, the majority of Chinese origin, and explores the danger of external cladding in high rise fires due to the large molecule hydrocarbon smoke and the acceleration of fires on the exterior of the building.

Modes of Attenuation

Radio signal reception is subject to propagation loss between transmitter and receiver. The technical term for this is link budget, which takes into account the RF power of the transmitter, radio wave losses at that frequency, and local factors such as building losses due to metal (especially in reinforced concrete structures) and reflective surfaces such as foil insulation on plaster board. These are fixed losses, and apart from known dead spots within buildings, radio communication can take place normally.

The following three factors account for additional losses due to the presence of a fire in the building:

1. Plasma effect, the heat haze above hot coals that makes the air appear liquid. This is in the visible spectrum, but it extends through the radio spectrum, causing large losses.
2. Particulates in the smoke. These are made up of low melting point metals such as copper and aluminium, as well as large hydrocarbon particulates from burning insulation, furniture and other plastics.
3. Water spray, due to the polarising covalent bonds in water, is particularly attenuative, increasing with the frequency of the radio used, which is why communication to submarines is done with Ultra Low Frequency "ULF" radio.

We will now examine each of these phenomena, the research on it, and effect they have on radio communication.

NOTE 1

In 2009, a massive blaze happened in the uncompleted Television Cultural Center (TVCC) in Beijing, causing one fire-fighter's death, seven injuries and more than 4 billion yuan in damage. The 2010 Shanghai fire destroyed a 28-story high-rise building, killed at least 58 people, and injured over 70 others. In addition, the Harbin Jingwei 360 degree Building fire in 2008, the Shenyang Royal Wanxin Building fire in 2011

1 Plasma Effect

The Plasma effect is due to ionisation from the direct radiated heat and the flame of fire. Much of the research conducted in this area has taken place in Australia and Botswana where they have frequent bush fires, and associated problems with radio communications "RADIO PROPAGATION IN FIRE ENVIRONMENTS" J A Boan(3) "EFFECT OF WILDFIRE-INDUCED THERMAL BUBBLE ON RADIO COMMUNICATION" Mphale, Heron, Verma(4) both confirm the losses in large scale open air fires, but what of buildings?

The paper "Wireless channel characterisation in burning buildings over 100–1000 MHz" by A.C.M Austin (5) models the effect of a fire with 1m radius flame (a relatively modest fire) and shows the local attenuation to be 10 dB worse than the no fire case within 10m of the fire or, put simply, 90% of the signal is lost.

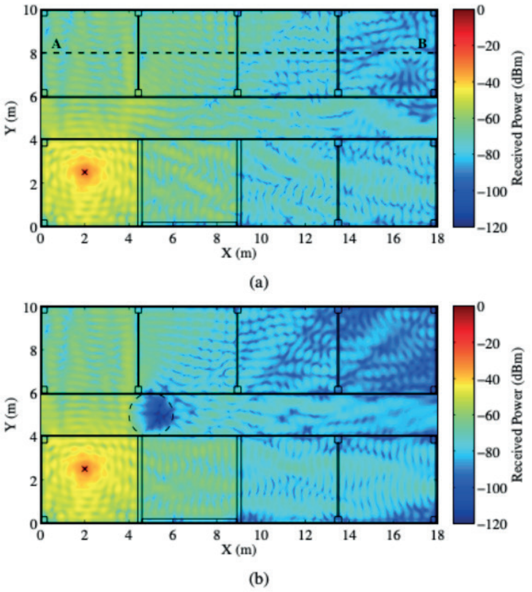

Fig.1 Power recorded on a slice positioned 1.3m above the floor at 450MHz (a) without fire and (b) 1m radius fire contained within the dashed locus (---) with fp = 850MHz and $v = 10^{10}$ Hz.

In the conclusions to Boans Paper(3) they state "Results from numerical experimentation has shown that refractive effects are small but accumulate over distance and present problems in large bushfires. Ionisation present in combustion is dominant in the short distance close to the flame front. Future work includes the development of a scattering model for small particles and further investigation of propagation effects with different fire scenarios. It has been noted that more in depth experimentation focussing on particular effects is needed."

2 Particulates in the smoke

In the Paper "Experimental Studies of Electromagnetic Wave Attenuation by Flame and Smoke in Structure Fire" by Yan-wu Li, Hong-Yong Yuan, Yang Lu, and Ru-feng Xu (6) they compare radio attenuation using various fuels, from alcohol to diesel, and differing smoke densities. They found that the attenuation is heavily variable, frequency dependant, and hard to predict in buildings. Attenuation ranges from a little over 1 dB (10% loss) at 300 MHz to 5.43 dB (72% loss) at 360 MHz. They conclude that the reason for this is the particle size in the smoke, which will vary depending on the fuel, but a good rule of thumb would be the blacker and more dense the smoke, the higher the attenuation.

As well as the fire attenuation experiments conducted by Mphale, Heron, Verma(4) ,they also added various metallic elements to the fires and noted the increased attenuation effects, and put this down to absorptive effects of the metals in the smoke.

3 Water spray

The paper "Electromagnetic-radiation absorption of water" by P. Lunkenheimer, S. Emmert, R. Gulich, M. Köhler, M. Wolf, M. Schwab, and A. Loidl (7) explains how water at room temperature closely resembles the behaviour of super cooled liquids. This is down to the polar nature of water, which allows the hydrogen molecules to bond with up to four neighbouring molecules. This is also why water is liquid not a gas at room temperature, and why it absorbs radio frequencies. More evidence is put in the work of C.C. Chen in the paper "attenuation of electromagnetic radiation by Haze, Fog, Clouds and Rain"(8)

This phenomenon is used in microwave ovens which use radio waves to heat up the water in food. Human beings, which are walking bags of water affect radio reception in a room.

Put simply, using water to prevent the spread of fire also prevents radio communication from passing through to the building.

Conclusions

In these days of WIFI and IoT radio is often perceived to be easier than running wires for communication, either electronic or voice, without first asking whether this a good idea, and whether it reliable not only when things are good, but when there is an emergency.

The evidence presented shows that radio communications in a real fire environment are completely different to the non-fire environment, and cannot be relied on for critical communications.

A serious discussion needs to take place with the Authorities in charge of building safety about operational procedures for the Fire Brigade in tackling high rise building fires particularly the communication between fire fighters and the officer in command in these situations. The adoption of a fire telephone system, as used in the US, or some other wired solution, may be appropriate to prevent fire fighter fatalities.

In the field of fire detection and alarms, BS 5839pt1 allows EN 54-25 radio devices, and in the early part of a fire, if the system is used as simultaneous evacuation system, it should work, but this cannot be guaranteed, especially if the fire is between the detector and the receiver.

In BS 8629 systems, where the fire brigade only use the system when the building has failed and evacuation is the only option, I would be very wary of the use of radio given the evidence shown here. Maybe this needs addressing in the next revision.

What this review of documents does highlight is how much we do not know, and how much research is still left to be done.

Bibliography

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