RADIOWAVE PROPAGATION MEASUREMENTS AND PREDICTION IN BUSHFIRES

Thesis submitted by

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ABSTRACT

Australian vegetation is fire-prone. Every year, wet and dry sclerophyll forests of Western Australia, southeastern Australia and grassland ecosystems of the northern part of the continent are subject to high intensity fires. The sclerophyll vegetation contains up to 2.71 % of the element potassium. The element exists in plants' organic matrix: attached to the oxygen-containing and carboxyl functional groups; in aqueous form such as potassium (K^+) ions surrounded by water; and as discrete particles in dried plant parts. Theoretically, temperature in the conflagrations can be as high as 2000ºC. During the high intensity bushfires, potassium atoms and salts are released from the plant structure as it crumbles into the combustion zone where the species are ionized. Up to 20 % of the potassium present in plants is ionized in a bushfire environment.

During suppression of the threat, high frequency (HF) - ultra high frequency (UHF) radio communications systems are in constant use by suppression crews in firegrounds. Despite their use, HF and very high frequency (VHF) radio communications are reported to be failing in extreme bushfire conditions. The reports of radio communication failure tend to be anecdotal and therefore warrant an investigation. This study aims at carrying out field and laboratory radio wave attenuation and phase shift measurements at HF to X-band frequencies in moderate intensity fires. Very high intensity bushfires often spread very fast and change direction rapidly therefore it is unsafe to set up equipment for measuring attenuation and phase shift in the fires. Consequently, numerical experiments were used to study radio wave propagation in very high intensity fires.

Propagation measurement data at radio wave (HF-VHF) frequencies through fire are scarce and that which is available lacks precision. It is also the purpose of the study to produce attenuation and phase measurement data at these frequencies. The field and laboratory measurements were carried out using a Radio Wave Interferometer (RWI) and Vector Network Analyzer (VNA - HP 8277C). RWI uses the same principles as Microwave interferometer (MWI) except that RWI works at radio frequencies. Electron density and momentum transfer collision frequency in moderate intensity bushfire plumes were estimated from the attenuation and phase shift measurements.

Laboratory and field measurements using a VNA - HP 8277C and RWI respectively in moderate intensity fires (700-1000 K) have revealed that electron density in the plume could range from 10^{14}-10^{16} m^{-3}. Theoretical calculations based on local thermal equilibrium in grassfires flames with temperatures up to 1200 K suggest that electron density could be up to 10^{17} m^{-3} if up to 20 % of the inherent potassium atoms are ionized.

There are at least two possible mechanisms that could lead to a significant signal strength reduction (attenuation) in bushfire environments. They are signal refraction due to thermal bubble and ionization-induced signal absorption in the plume. Electrons, which result from thermal ionization of potassium in the fire, transfer energy from the incident radio wave to the fire plume through collision with inherent neutral particles. The transfer of energy can significantly attenuate and induce a phase shift on radio wave signals. Experimental work carried out in the project suggest that radio wave attenuation is significantly higher at UHF and X-Band frequencies than at HF. Field radio wave propagation measurements at 1.50 m above the seat of a moderate intensity grassfire revealed that 30 MHz signals can be attenuated by up to 0.03 dB/m while 151.3 MHz signals were attenuated by up to 0.05 dB/m. An intense cane fire attenuated 151.3 MHz signals by 0.05 dB/m. The attenuation effect was observed to increase when X-band (10.0 -12.5 GHz) signals were considered. Attenuation coefficients up to 4.45 dB/m were measured.

Phase shift induced on the signals was also observed to increase with the increase in frequency band (low for HF and high for X-band). A 30 MHz signal suffered a 3.08º phase shift in the moderate intensity grassfire whereas in the X-band frequencies, a phase shift of up to 29.31º was observed in a fire of about the same intensity.

Numerical experiments have shown that signal loss due to refraction is frequency dependent in very hot regions of bushfire plumes. X-band waves are more affected than VHF waves. Numerical experiments predicted maximum attenuation coefficients of 0.11 dBm^{-1} for 150 MHz and 0.31 dBm^{-1} for 3 GHz radio waves when they propagate about a meter above fuel-flame interface of a 90 MWm^{-1} bushfire with fuel potassium content of 0.50 %. Theoretical studies also revealed that; for potassium content of about 0.20 %, a collimated beam of radio signals (10 cm wide) propagating at grazing angles to the fuel-flame interface of a very high intensity bushfire (1600 K) could suffer attenuation coefficients of about 1.45 dBm^{-1}. This effect is calculated to decrease with the increase in height above the combustion zone. For very high intensity bushfires in fuels with high potassium content (e.g., up to 3.00 %), attenuation by refraction is likely to be the most significant form of radio wave energy loss for collimated beams propagating at grazing angles to the fuel-flame interface.

The Line-Of-Sight (LOS) radio wave propagation measurements in moderate intensity vegetation fires (700-1000 K) have shown that signal attenuation is plume temperature and frequency dependent. Transmission through hottest region of the fire (combustion zone) suffers significant signal strength loss whereas low attenuation has been observed at cooler regions of the plume. This could be explained by the fact that “collisional plasma effect” on radio waves is more pronounced at combustion zone than at the thermal plume region of the fire as the effect is temperature dependent.

Bcontinent with a potential combustion zone temperature of 2000ºC. These bushfires have a potential to adversely affect LOS radio wave communications when transmission is through the hottest part of the fire. It must be noted that radio wave communication blackout could even occur at temperatures as low as 1300 K provided that the fire is sufficiently ionized.

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