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Background Radio Frequency Interference Measurements for Wireless Devices in the Electricity Supply Industry

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BACKGROUND RADIO FREQUENCY INTERFERENCE MEASUREMENTS FOR WIRELESS DEVICES IN THE ELECTRICITY SUPPLY INDUSTRY

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Abstract
Incorporation of radio controller units into heavy equipment used in the electricity industry provides numerous advantages including: improved electrical isolation between plant and operator, ability to incorporate an additional remote operator, and reductions in vehicle wiring and hydraulic hoses for equipment control. However, secure operation of vehicles and plant incorporating radio control rely on establishing suitable levels of immunity to possible radio frequency interference. Interference levels in close proximity to high voltage power lines are of special concern to the electricity industry. This paper reports on a preliminary investigation into quantifying the levels of background radio interference at such locations in order to develop required immunity specifications for radio controlled equipment.

1. Introduction

The electricity supply industry has recently embarked on implementation of radio control into their maintenance and construction vehicles. These vehicles, primarily Elevating Work Platforms (EWP), are used extensively by electricity utilities for many routine operations, including maintenance and repair of live overhead power lines. EWP units have historically been operated using hydraulic controls and actuators. In a direct attempt to increase the effective electrical isolation levels of vehicle components these controls are now being replaced with radio control.

Hydraulic control lines within EWP booms are prone to gradual build up of contaminants (dirt, oil, etc.), which increase the possibility of current tracking if any component of the EWP comes in contact with live overhead lines. This compromises the insulation integrity of the boom. Replacement of hydraulic controls with radio control units allows the number of hydraulic control lines within the boom to be reduced and thus lessen the build up of contaminants.

Radio control operation of EWP units also allows the introduction of a remote operator to take control of the EWP movements in emergency situations, with near immediate transfer of control in circumstances when required. In addition, if remote ground operators are able to utilise a radio controller, it eliminates the need for them to approach a potentially live chassis in an emergency where the EWP has come in contact with live overhead lines. While the introduction of EWP radio control units is already being undertaken, manufacturers of the radio control units seem unwilling to guarantee their operation in the electromagnetic interference (EMI) environment that exists in close proximity to live overhead lines.

The range of environmental variables associated with possible detrimental effects on the radio control that were of concern for this study include close proximity to large magnitude 50Hz voltages and currents, radio frequency interference initiated by transient over voltages from lightning and distribution system circuit switching operations, radio transmissions from other nearby devices, and the required range available to the radio control units. This paper covers two aspects of the security of EWP radio control unit operation:

(i) Interference from external sources emitting radio frequency emissions, and
(ii) The effects of electromagnetic interference (EMI) from live overhead lines.

2. Elevating work platform security of operation

The main concern for electricity utilities is the safety of EWP operating personnel and the public. Operator safety issues include environmental factors (especially during storm conditions and wet weather when crews are at their most active), integrity of hydraulic systems, electrical insulation including inadvertent contact with live conductors and contamination issues, fire and adequate staff training. Various codes and standards [1, 2] have been developed to address these concerns in regards to EWPs. A recent paper [3] describes the above mentioned issues and the proposed changes to the relevant Australian Standard [4]. These changes are intended to improve operator and public safety. However, radio control specifications and immunity requirements are not expressly dealt with in these codes and standards.

There have been some isolated cases of incidents involving EWP units whereby the operator has not been able to operate the hydraulic controls from within the bucket of the EWP unit due to incapacitation. In these cases a remote operator has had to board the EWP vehicle and descend the boom using the remote controls on the EWP vehicle. There have also been incidents whereby the boom has come into contact with live lines to the point where the EWP vehicle becomes live and fault current to earth is initiated (see Figure 1). A combination of these two types of incidents would be a suitable argument for establishing a remote operator away from the vehicle using a radio control unit.

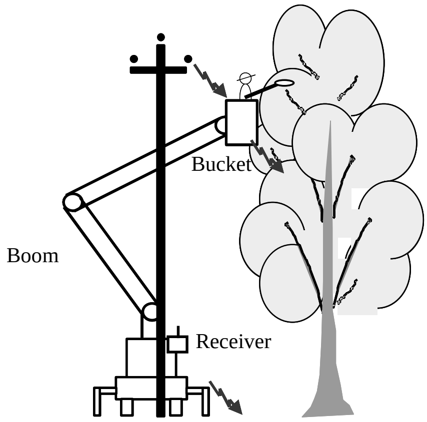

Figure 1: Sketch of EWP operating close to overhead power lines and nearby trees

3. Elevating work platform radio control

Radio controls for EWP units are usually modular units that can be configured for cranes, vehicles, or any industrial machinery. The number and complexity of controls can thus be configured to match just about any application. For the EWP units the radio control transmitter devices are fitted with weather protected joysticks, an emergency stop push button, control indication, power on/off push buttons, key operated lockout switch, and channel selection switches (if available). The receiver units are designed to operate the hydraulics of the EWP via control valves.

A typical range for a remote operator of an EWP is approximately 20m. This ensures sufficient distance for isolation from a potentially live vehicle chassis. The required range of operation will vary across work sites. The radio controllers should be able to operate without malfunction up to 50m from the vehicle. A range of 100m is specified by most equipment suppliers [5]. It is proposed that the remote operator would only operate the bucket and boom in a situation whereby the main operator (in the bucket) has become incapacitated or there is a danger of loss of control.

3.1 Interference from other wireless devices

The typical operating frequency bandwidth of the radio control units and similar units available overseas is specified as being selectable within the range of 400 to 500MHz. The specific operating frequency band used by most EWP radio controls in Australia is 433 to 434MHz. This operating frequency allows the radio control units to be operated unlicensed within Australia provided the radio frequency power output is below 25mW and the duty cycle of operation is less than 10% [6]. There are similar requirements for such devices operating within Europe [7].

Other wireless devices also using the 433 to 434MHz band in Australia that may be of concern to the operation of the EWP radio control units from an interference perspective include:

- Wireless controlled video, high definition cameras,
- Wireless door openers,
- Wireless amplifier-loud speaker combinations and wireless headphones,
- Medical sensors (range of up to 1km), and
- Wireless alarm systems (range of 100 to 300m).

On the market there are high power transmitters available for wireless transmission used in telemetry, telecontrol and remote monitoring equipment with output power up to 1000mW. UHF transceivers are also available at similar frequencies with emitted power of 500 to 5000mW and a range of up to 50kms.

Spectral leakage from nearby frequency bands may also contribute to interference. Devices that have significant power output levels and operating at nearby frequency bands include:

- Trunk radio
- Household radio modems (range up to 1.5km)
- Older digital phone networks
- Remote car door and garage units
- Radio controlled cars (difficult to control use of)

To assist with the security of operation (interference immunity), the more complex EWP radio control units have a number of channels available using FM narrow bandwidth modulation. Typically 8 to 32 channels will be available and selection can be either manual or automatic. Automatic control of channel selection allows the unit to be switched to an alternative bandwidth if interference from an external source becomes significant. It is noted however that the bands for the various channels are not separated by a large expanse of frequencies, usually 12.5kHz to 50kHz, and interference from one or more of the above mentioned devices may indeed 'black out' a number of available channels.

To ensure that similar units do not interfere with each other, the manufacturers provide address encoding. Some manufacturers specify up to 20 bits encoding for addresses (over 1,000,000 separate addresses). CRC error encoding or a similar alternative is also provided with the transmitter signals to ensure commands are received correctly by the receiver unit.

3.2 Interference from electrical disturbances

Live overhead powerlines will generally only produce significant electromagnetic fields at frequencies at or near the nominal power frequency, i.e. 50Hz. If electrical disturbances exist on the power lines that comprise of components of frequencies other than the nominal system frequencies, electromagnetic fields will also be produced at the component frequencies. Low frequency power quality disturbances such as harmonic distortion, voltage fluctuations, frequency deviations, voltage sags and swells, momentary interruptions, notching, and unbalance all occur at frequencies well below the operating frequency of the EWP radio control units.

High frequency power quality disturbances such as impulsive and oscillatory transients may contribute to significant radio communication interference [8]. These high frequency power system phenomena can arise due to lightning strikes, switching events, or system fault conditions. High frequency oscillatory transients can occur during back to back switching of capacitor banks, however frequencies typically remain below 0.5MHz [9]. Fault conditions that excite the natural response of the system can create significant oscillatory transients of the order of 1-5MHz depending on the system configuration and location of fault. This brings oscillatory transients into the range of HF radio communication devices.

Lightning strokes exist for only 50 to 100μs, and these may be multiple return strokes within a period of 1 second [8]. Although capturing of current and voltage waveforms due to lightning strikes is difficult, it is generally accepted that initial rise times of approximately 0.5-1.5μs are typical [10]. Thus most of the energy associated with lightning strikes will be concentrated at frequencies less than 1MHz. There is a small amount of energy above this frequency and indeed down to dc. Significant interference due to lightning strikes can thus occur for HF and lower range VHF radio communication devices.

Arcing, or gap type discharge, and the effects of corona discharge have been reported to exist at significant levels on HV and EHV systems for frequencies up to 100MHz. Beyond this frequency the strength of the RF interference created drops off at a rapid rate [11, 12]. Although not of primary concern it is possible that electromagnetic interference from inductive coupling paths may have an effect on the security of operation of the EWP radio control system.

4 Field measurements of interference

Levels of interference due to overhead power lines are rarely reported above 100MHz [12-14]. In [13] significant interference fields were found around the proximity of faulty equipment, switches and insulators. The randomness of interference effects combined with the high resolution required to measure effects at frequencies above 1MHz ensures field measurements are difficult.

Field measurements of background radio frequency interference for this study were undertaken at various locations within the customer base areas of TransGrid, Integral Energy and EnergyAustralia. The purpose of coordinated field measurements was to determine if any significant background radio frequency interference levels existed at frequencies utilised by EWP radio controller units near typical working locations.

The locations identified for measurements included those in close proximity to overhead power lines, substations, and locations adjacent to customer installations. Sites with suspected high probability of background interference that were proposed for the study are listed in Table I.

Table I: Field measurement sites

Site	Description
1.	500kV Substation
2.	330kV Substation
3.	132kV Substation
4.	66kV overhead feeder
5.	33kV overhead feeders
6.	11kV overhead feeder
7.	Utility workshop and depot
8.	Remote control aeroplane airfield
9.	Digital television and communication towers
10.	Mobile phone tower
11.	Hospital and radiology unit
12.	Shopping centre
13.	Office complex
14.	Computer laboratory
15.	HV DC lines at a Railway Station

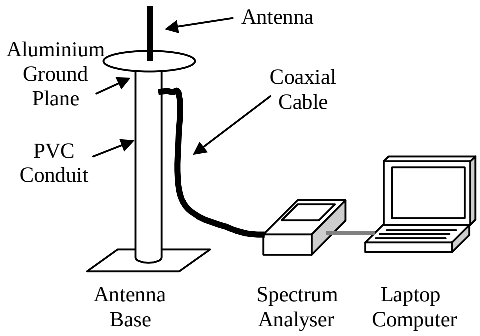

Figure 2: Field measurement test setup

4.1 Measurement procedure

Background radio frequency interference levels were obtained to establish test limits for operation of the EWP radio controller units. Measurement of background radio interference levels was completed using a handheld spectrum analyser, high bandwidth antenna developed for the project, and computer for data storage and analysis. The field measurement test setup is illustrated in Figure 2. Measurements were completed with the antenna and spectrum analyser located immediately adjacent to the live overhead lines where possible. At some locations access was limited and thus measurements had to be taken at distances of up to 5 to 10 metres from overhead lines and other sources.

To ensure the radio frequency emissions from arcing were captured (i.e. to emulate corona discharge, surface discharge, etc.), at numerous sites the arcing was synthetically created by contacting the live overhead lines with insulated testing poles. This was completed from the EWP bucket at a distance of 1 to 2 metres from the lines and from ground level at various locations.

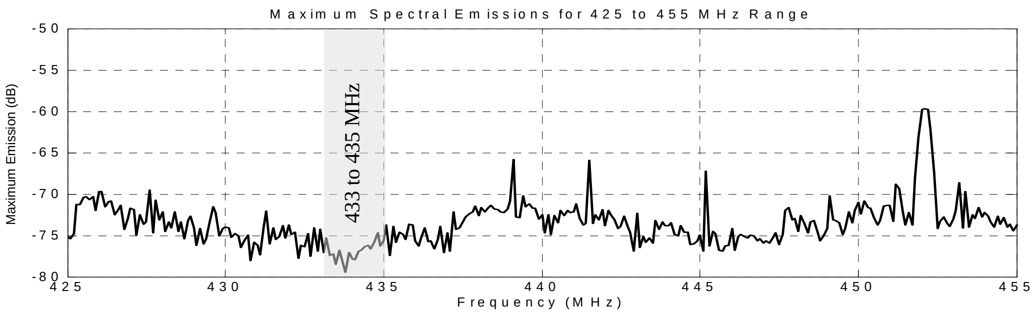

Figure 3: Maximum level of background interference for frequency range 425 to 455MHz

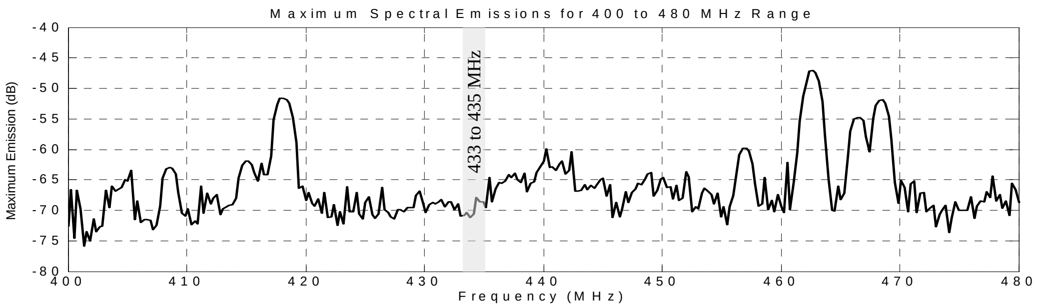

Figure 4: Maximum level of background interference for frequency range 400 to 480MHz

Three sets of measurements were obtained at each of the sites listed in Table I. Each set of measurements was obtained using the maximum peak hold function of the spectrum analyser. The three sets of measurements were:

(i) 425 to 455MHz sweep to identify interference equivalent to or adjacent to operating frequency of the EWP radio control units.

(ii) 400 to 480MHz sweep to identify interference adjacent to operating frequency of the EWP radio control units which may have spectral leakage into radio control unit signals.

(iii) 0 to 400MHz sweep to identify interference at lower frequencies to investigate the assumption that interference from live overhead lines will be at the lower end of the frequency spectrum.

4.2 Background interference levels

The first set of measurements obtained at each site was of the maximum recorded samples of background interference in the frequency range 425 to 455MHz. Figure 3 illustrates the overall maximum background interference levels across all sites obtained within this bandwidth. The spikes of background interference within the bandwidth were identified at the various sites including: 500kV substation, 330kV substation, and adjacent to telecommunication towers.

In Figure 3 it can be seen that the background radio frequency interference levels are greater at other frequencies than within the 433 to 435MHz range of interest. However, the possibility of spectral leakage from neighbouring frequencies and the inevitable use of devices not captured during these specific field measurements suggests the eventual immunity level (i.e. the background interference levels which will not affect the EWP radio controller unit) should be specified above the values within 433 to 435MHz. As other frequency bandwidths outside this narrow bandwidth may also be utilised by some types of EWP radio controller units, immunity levels may be required to include other bandwidths within the 425 to 455MHz range. This is an area that requires further ongoing investigation as new EWP radio controller units are introduced onto the market.

The second set of field measurements was a repeat of the first test with a broader frequency sweep of 400 to 480MHz. As the same number of sample frequency points are utilised by the spectrum analyser there is some lost resolution in completing frequency sweeps over the wider range, and thus results become indicative. Sufficient resolution is retained to identify major background interference that may have an affect on EWP radio controller units. Figure 4 illustrates the maximum background interference levels obtained over all sites within 400 to 480MHz.

Some of the peak magnitudes identified in Figure 3 are also present in the Figure 4, even with the reduced resolution settings of the spectrum analyser. As illustrated in Figure 4 significant background levels exist both above and below that of the frequencies utilised by the EWP radio control units. The spikes of background interference within the 400 to 480MHz bandwidth of Figure 4 were obtained at various sites including; the railway station, the 500kV substation, and adjacent to hospital and mobile phone tower sites.

Figure 5 illustrates the sweep of frequencies from the lower range of the spectrum analyser, i.e. 100kHz, up to that of previous sweeps. As suspected there is much greater levels of background radio frequency interference at lower frequencies. This was general to all sites from which field measurements were

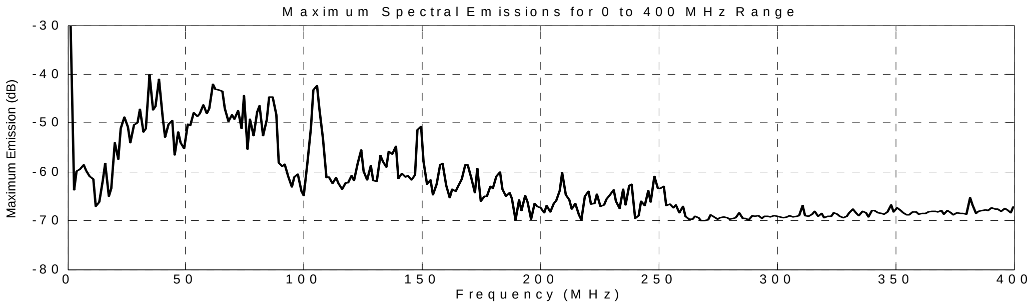

Figure 5: Maximum level of background interference for frequency range 0 to 400 MHz

obtained, and especially those immediately adjacent to live overhead lines. This aligns with the evidence from [15] that in general significant radio frequency interference from live overhead power lines will be limited to frequencies below 200MHz.

The background interference levels from Figure 3 can be compared with the EWP radio control unit transmitter output measured by the spectrum analyser at various ranges as shown in Figure 6. Only at close proximity is the transmitter output signal level above that of the measured maximum background interference levels. It is noted that the maximum interference levels measured may only exist for short periods of time, as the maximum hold function was used with multiple sweeps of the bandwidth of interest. The probability of the maximum background level and command signal of the EWP radio controller existing at the same time may be quite small in most cases. However, it does identify the possibility of significant interference existing at some sites.

4.3 Specification of interference immunity

It is proposed that the background radio frequency interference levels of Figure 3 immediately adjacent to 434MHz be used to determine the minimum test limits for specification of EWP radio controller immunity. Incorporating the neighbouring peaks of background interference suggests a level of approximately –70dB (-40dBm) should be used as the required immunity level. A small allowance is given for interference sources not identified in the field measurements. Note that the specified test limit appears uniform for practicality of implementation rather than varying over the frequency range in a similar manner to that of measured values.

5 Laboratory measurements

Laboratory testing of a sample EWP radio controller was undertaken as part of the investigation into EWP radio controller security. The laboratory tests included a comparative calibration of the equipment used to obtain field measurements with laboratory equipment, determination of the operating range of radio control units, and establishment of background radio frequency interference levels which produce significant errors at the EWP radio controller receiver.

A single EWP radio controller unit on loan from a representative supplier was used for all the laboratory tests. No comparative tests have been undertaken using EWP radio controller units from other manufacturers/suppliers.

5.1 Field measurement equipment performance

To establish the performance of the antenna developed for the field measurements, the reflection coefficient of the antenna was determined using a laboratory network analyser. The reflection coefficient measured was approximately 6.3dB at 434MHz, illustrating minimal losses, and therefore satisfactory performance of the antenna.

The coaxial cable connecting the laboratory network analyser with the antenna had measured attenuation of 0.2 dB at 434 MHz. This is also to be included in the power losses of the entire antenna configuration.

5.2 Radio controller unit under test

The sample EWP radio controller unit under test consisted of a transmitter and receiver unit. The receiver unit had four LEDs which indicated the status of the signal transmissions, allowing indication of valid data being received, emergency stop activation,

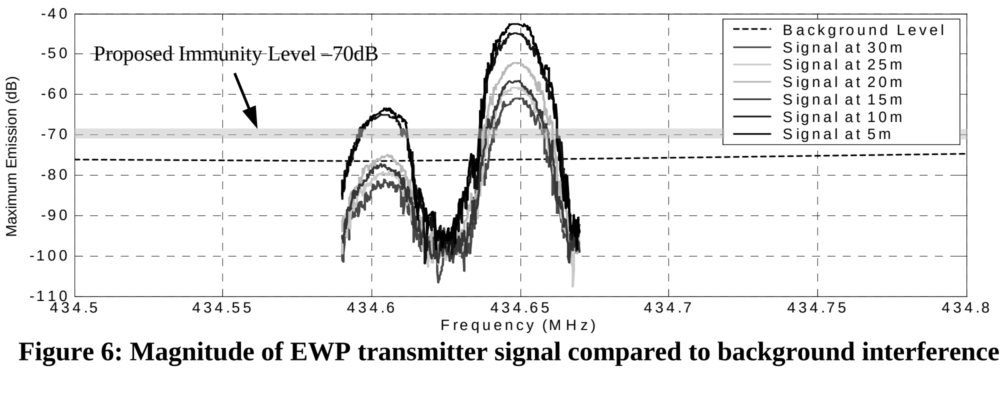

Figure 6: Magnitude of EWP transmitter signal compared to background interference

power on and off, and establishment of an operational error condition (excessive signal error or internal circuitry error).

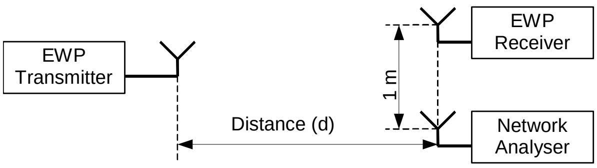

Figure 7: EWP and laboratory equipment set up

To establish the working range of the EWP radio control unit testing of the transmitter signal attenuation over various distances was undertaken. This involved measurement of the transmitter signal power over distances of 5m to 30m. Results of these tests are presented in Figure 6. The laboratory setup for the attenuation measurements is illustrated schematically in Figure 7. The EWP radio control unit receiver and broadband antenna were placed at a distance 1 m apart, while the transmitter unit was operated at increasing distances perpendicular to the midpoint of the receiver and antenna. The antenna was connected to the laboratory network analyser via the same coaxial cable used for field measurements.

Table II: Interference signal levels at which errors (LED indication) were established

Distance (m)	Test 1 (dB)	Test 2 (dB)	Test 3 (dB)
5	No errors	No errors	No errors
10	No errors	No errors	No errors
15	-52.16	-36.36	No errors
20	-56.66	-54.56	-35.66
25	-52.36	-40.36	-35.36
30	-55.76	-43.06	-45.46

The setup in Figure 7 was also utilised to determine the immunity levels of the EWP radio control receiver unit. This was achieved by using the network analyser as a ‘white noise’ interference source by increasing the magnitude of interference until the receiver signalled erroneous transmissions. The results of these jamming test are summarised in Table II. The sample EWP radio control unit provided immunity above that of the -70dB suggested as a suitable immunity level in Section 4.3.

6 Conclusions

Field measurements of background radio frequency interference at operating locations of radio controlled vehicles used by the electricity industry have been undertaken. Results suggest that it is unlikely that significant levels of electromagnetic interference derived from the currents and voltages existing on live overhead power lines will occur at frequencies within the 400 to 500MHz frequency band used by the radio control units. Further measurements are required at each site to establish variations in background levels over periods of time and to also allow improved statistical analysis to be performed on the results.

The frequency band selected for the operation of the elevating work platform radio control units is of some concern as this frequency band is shared by a significant number of unlicensed users at various operating power levels and duty cycles. It is perceived that this frequency band will only become more crowded as Australia adopts similar allocations of frequencies as is currently being adopted in Europe. A proposed immunity level to such interference has been established.

7 Acknowledgements

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