Resolving Safety-Critical EMI Problems Between AM Transmitters and Cranes Using a 3D Field Solver

By Marcelo Bender Perotoni and Roberto Menna Barreto

Electromagnetic fields from two high-power AM transmitters close to a construction site induced dangerously high voltages in crane booms, damaging equipment and injuring workers. With construction halted, a solution was urgently required. Electromagnetic simulation was used to identify the cause of the problem when conventional on-site analysis approaches failed, and allowed the engineers to compare possible countermeasures quickly. The chosen solution, a large inductive coupling to the ground, was successfully implemented and construction was able to continue.

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Background

Electromagnetic interference (EMI) is a problem that can affect devices at all scales, and can pose serious risks to workplace safety and the reliability of equipment. While techniques exist for designing countermeasures against expected EMI problems, the unique properties of each operating environment mean that unforeseen issues can arise in operation.

One example of such an EMI problem arose on a building site in the urban coastal area of Rio de Janeiro. Two cranes – a large crawler crane on caterpillar tracks (Figure 1a) and a smaller truck-based crane (Figure 1b) – were deployed to the site to help to construct a pier

Figure 1 • The two cranes used on the construction site.

Figure 2 • Detail of the burnt pulley, showing the damage to the sheave and cables.

The source of the interference was quickly identified: two AM transmitters located approximately 230 meters from the construction site (Table 1, Figure 3). The antennas operated at 100 kW and the maximum radiation direction from the antennas was directed towards the construction site.

The obvious first solution was to ground the whole vehicle using a thick chain connected to the crane structure. However, this did not alleviate the problem. Keeping the booms retracted was also not an option, since they had to be extended for the crane to be able to move and carry its load. Therefore, other alternatives were sought.

Searching through the literature showed that while the problem of electromagnetic induction in cranes is known, studies are limited, and most of the suggested countermeasures are designed for much higher frequencies. Very little information was found about induction caused by AM radio.

This meant that an in-depth study of the problem was necessary. In-site analysis was limited and compli-

for oil transport. However, once on site, both cranes became victims of severe EMI issues.

Workers using the cranes reported moderate and intense electrical shocks from the equipment, strong enough even to cause skin burns when the boom was touched with bare hands. In addition, the operators of the truck-based crane reported that its electronic systems became inoperative. The intensity of these electrical shocks was dependent on the orientation of the boom, time of the day and atmospheric conditions, becoming stronger as the booms were extended. The induced voltages were so great that the pulley on top of the boom caught fire (Figure 2). The cables and the structure were both damaged and had to be replaced.

Construction was halted, due to the clear risks to worker safety and equipment reliability. Due to the major financial losses involved, the problem had to be solved as quickly as possible, both in respect to the construction of the pier itself, and its subsequent operation.

AM station #1	AM station #2
Frequency: 1,280 kHz	Frequency: 900 kHz
Power: 100 kW (day) and 50 kW (night)	Power: 100 kW (day) and 50 kW (night)

Table 1. Details of the AM stations.

Figure 3 • The antenna towers as seen from the construction site.

cated to the difficulty of access, and the large number of possible real world scenarios (for example, different crane positions and boom inclinations) ruled out practical evaluations. For this reason, computer simulation was employed to model the situation. Electromagnetic simulation allowed multiple scenarios to be evaluated, and offered understanding of the fundamental physics pertinent to the problem.

Computer Simulation

Objects resonate at integer multiples of the wavelength, as well as at geometric fractions of the wavelength (½ wavelength, ¼ wavelength and so on). AM station #1 transmits at the frequency of 1,280 kHz, which corresponds to a wavelength of 234.4 m. The fractional resonant lengths for this frequency are 117.2 m, 58.6 m and, crucially, 29.3 m – a critical length for the cranes. At this length, the cranes behave as an antenna, capturing the incoming RF energy.

The first stage of characterizing the coupling between the cranes and the antennas is to calculate whether the crane lies in the antenna's farfield. The transmitting antennas are considered as monopoles, since they are vertical and the ground (which in this case includes the sea) is considered a good conductor in this frequency range.

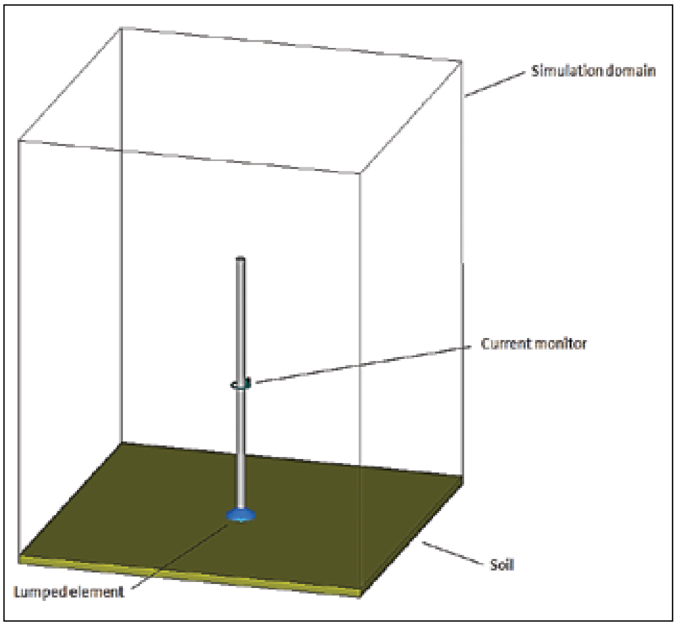

Figure 4 • The initial crane model.

For a monopole, the farfield limit d is given by Balanis [1] as:

$$d = \frac{2D^2}{\lambda},$$

where D is the largest antenna dimension and λ is the wavelength in question. The results of this calculation for the AM stations are shown in Table 2:

	Wavelength λ (m)	D (m)	d (m)
Station #1	234	59	29
Station #2	333	83	42

Table 2 • Farfield distances of the AM stations.

Since the cranes are both around 230 m from the antennas, they can be considered as residing in the antenna's farfields. This means that the analysis focused on treating the crane as a resonant structure.

The simulated model is shown in Figure 4. The crane was modeled in CST MICROWAVE STUDIO® (CST MWS) [2] as a simple vertical metallic cylinder, 1 meter from the ground, with a radius of 1 m. The cylinder has a height of 60 m. The ground is modeled as sandy soil, using the electrical properties from the CST MWS material database. Because the crane is located in the antenna's farfield, the excitation is modeled with a plane wave. The soil has a depth of 2 meters, with open boundaries to model an infinite expanse. The open top face was set as a normal perfect matched layer (PML).

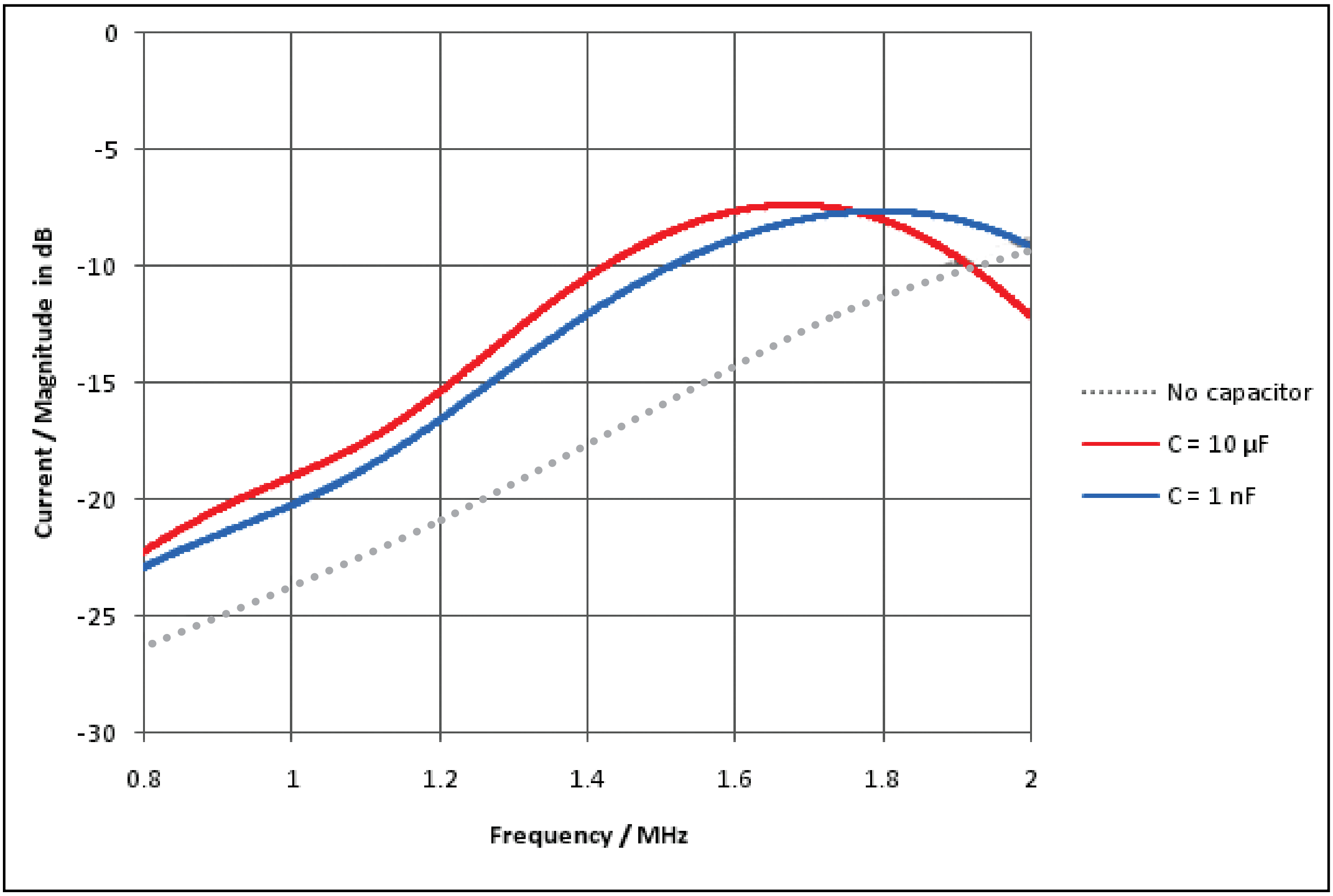

Figure 5 • Received spectrum power (in dB) of the current measured on the probe placed on the boom. The frequency spans 800 kHz to 2 MHz.

More sophisticated mechanical models were not available, and because of the urgency of the situation, a simplified model was deemed sufficient for the analysis.

Since the problem was caused by the size of the crane structure, the obvious approach was to decrease the boom size. Although it is impossible to shorten the mechanical structure, it is possible to make it electrically smaller. To do this, additional elements can be added between the boom and the ground, causing the boom to resonate at higher frequencies.

By analogy with standard antenna theory, the first element investigated was a capacitor. The capacitance was implemented with a lumped element, as shown in Figure 4, and the current was measured at a probe on the boom. The results from this study are shown in Figure 5.

From the results, it's clear that adding a capacitance actually increases the circulating current in this part of the radio spectrum. Attention therefore turned to the dual element of the capacitor, the inductor. Figure 6 shows the results for two different inductor values. These provided a reasonable decrease in induced current magnitude at around 1 MHz, suggesting that an inductor is the element of choice for alleviating the problem.

The next numerical evaluation analyzed the scenario where the hook was hanging, forming a loop. Loops are well known for their capacity for picking up magnetic fields, and so the combination of the crane boom and the dangling cable represents a potential problem. Figure 7 shows a simple 3D model taking into account the hook hanging 40 meters from the boom top, where the green dot is a probe that records the electrical field at 20 cm away from the cylinder.

As illustrated in Figure 8, the presence of a loop creates a resonance. As the loop area becomes larger, so do the electric fields. Further simulations showed that with larger areas, the maximum electric field amplitudes corresponded with lower resonances, increasing the levels of hazardous electric fields on the structure.

Practical Implementation

Once simulation had established that adding an inductor offered a solution to the problem, attention

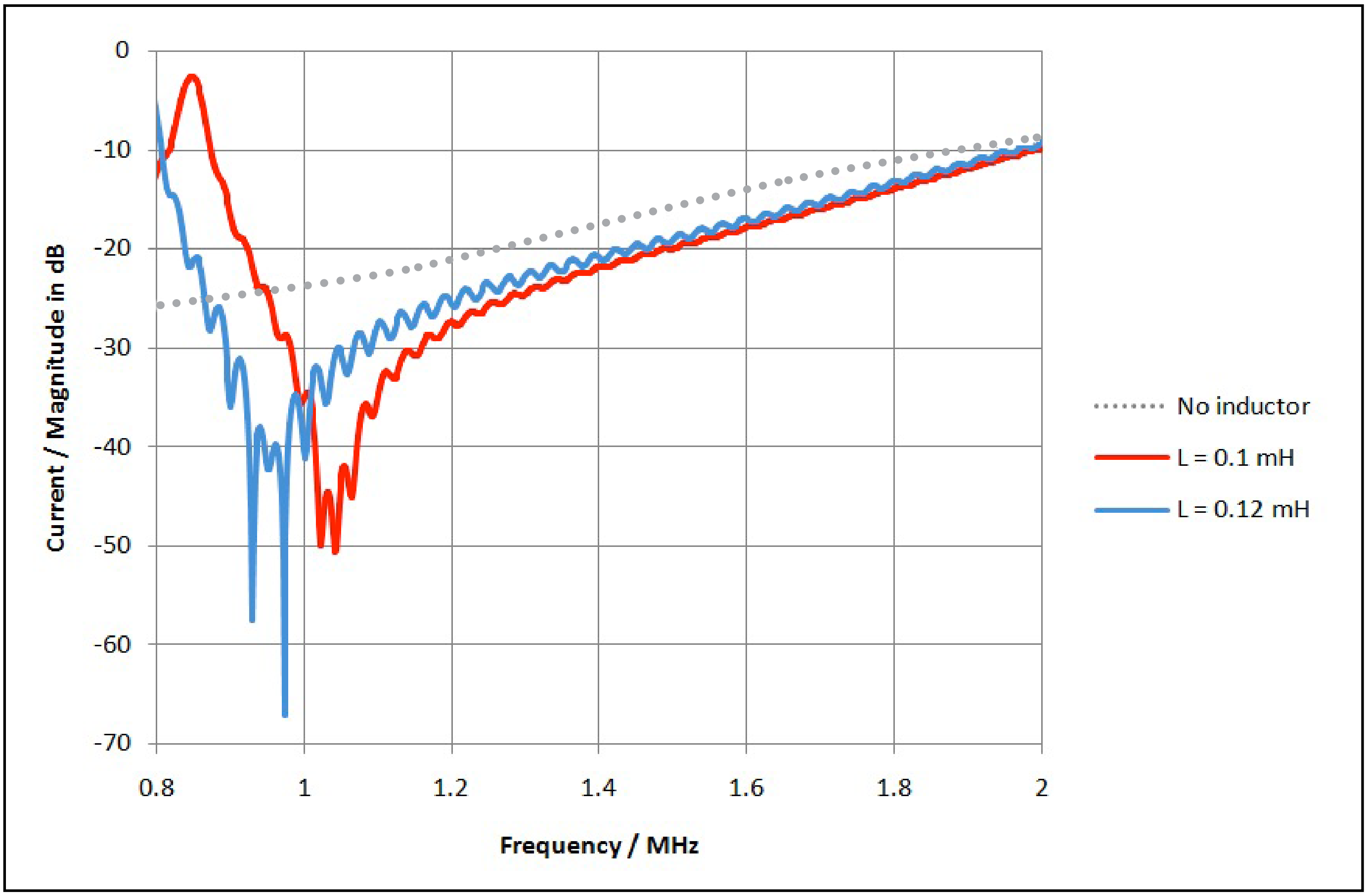

Figure 6 • Received spectrum power (in dB) as in Figure 5, with an inductor in place of the capacitor.

turned to implementing this solution in the real world. Due to physical constraints and the quick and dirty modeling, the exact value of inductance found in the simulation was not important. More important was the principle revealed: that an inductive coil can inhibit resonances in the AM frequency bands.

The chosen implementation is shown in Figure 9. 85 meters of cable with cross-section 2.5 mm^2 were wound around the hydraulic jack of the crane. This acted as the ferrite core of an inductor, giving the coil the correct inductance level to prevent the EMI problems. One end of the coil was connected to the hook, and the other grounded to a suitable point nearby. During operation, the wire between the hook and the coil forms a catenary, whose length and shape can be manually controlled by the operators down on the ground.

Tests were performed with the boom angled to produce the maximum induced voltage. These proved that the implemented modifications worked, allowing safe, shock-free operation. The site was officially deemed safe

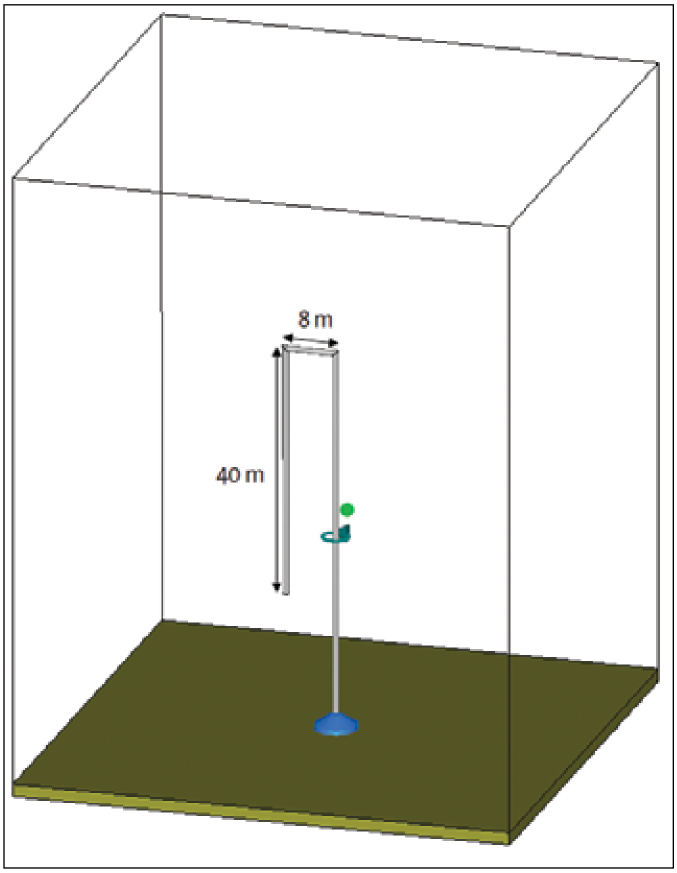

Figure 7 • The loop model. The green dot highlights the position of the field probe.

again and construction resumed, with no further financial or schedule losses.

RF Frequency Considerations

The stopgap solution detailed above allowed construction to resume. However, the actual operation of the finished pier also needed to be examined in detail. As well as the electric shock risk, other considerations included the protection of electronic systems against EMI, the exposure of workers to non-ionizing radiation and interference with transmissions from the radio stations.

The main exposure hazard for RF energy is the heating of body tissues. At FM radio frequencies (around 90 MHz), the dimensions of the body mean that it acts as a good antenna. For lower frequencies such as the AM radio band, this effect is almost negligible, since the AM wavelength is so much larger than a human body.

Instead the biggest concern to take account for the protection of workers in the pier was electrostimulation—the effect of an electrical current passing through the body. If the voltage between the structure and the worker is high enough, arcing can occur, causing burns.

Protective measures against these currents include insulating boots and gloves for workers who interact with the crane or suspended cargo, and appropriate training for involved staff.[3] To help avoid shocks and burns, the voltage of metal parts should be verified before they are touched. As an example, the United

Figure 9: (a) The implemented coil and (b) the wire connecting the hook to the coil.

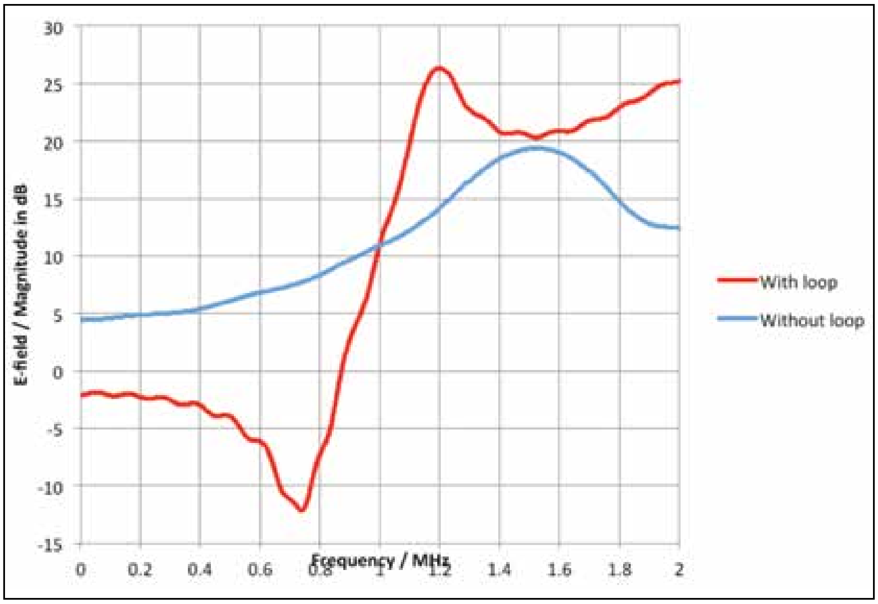

Figure 8 • The response (absolute electric field measured at the probe position) for the cases with loop (red curve) and without loop (blue curve).

States Navy has adopted 140 V as a maximum allowable voltage across the body in this frequency range.[4]

The voltages pose particular risk to the crane operator. While the crane cabin should be grounded for various reasons, this will have little influence on the high voltages at the bottom of the crane. Instead, the best solution is to isolate the operator from the voltage on the crane and load. This can be done by isolating the driver from metallic parts such as the control pedals, by replacing the cables or hooks with non-conductive materials such as nylon and Kevlar which are strong enough to support the load from the hook, and operating the crane remotely using a wireless control system.

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References

[1] C. Balanis, *Antenna Theory: Analysis and Design*

[2] CST - Computer Simulation Technology, www.cst.com

[3] R. Stricklan, “Safety Training for Workers in High-RF Environments”, Above Ground Level (AGL) magazine, March 2010, Vol. 7, No. 3

[4] R. Olsen, J. Schneider, R. Tell, “Radio Frequency Burns in the Power System Workplace”, IEEE Transactions on Power Delivery, January 2011, Vol. 26, No. 1