Near Weak field coupling for large bus connections

Paul M. Record MIET, C.Eng
Institute for sensors signals and systems (ISSS),Engineering and Physical Sciences,Heriot-Watt University,Riccarton Campus,Edinbugh EH14 4AS

p.record@hw.ac.uk

Abstract

Electric vehicles typically have a large array of storage cells and for efficient operation each cell should be monitored individually. In other areas industrial processes need to be monitored often in harsh conditions. A conventional approach is to physically connect sensor and actuators to long buses. High data rates demand high frequency buses but direct connection means that loading and attenuation can be severe and impractical if a large number of devices need connection. The alternative is free space radiation. The latter was investigated for track to train communication at 2.4GHz [7] In the limited space of battery compartments rectangular wave guides are impractical, however micro strip lines can made compact enough to fit in these locations. By weakly coupling a sub-wavelength antenna to a micro-strip transmission line simulations and experimental data over frequencies between 600 and 1 GHz show it is possible to couple up to 100k devices without unduly loading the line. The line is not limited in length and radiation is so low that is little interference between adjacent devices and the surrounding medium. It has the added advantage that each node is electrically isolated from each other and the transmission line.

Keywords : Transmission line, EM coupling, large bus communication

1.0 Introduction

Pollution from transport in cities across Europe and China frequently exceeds many regulations. The damage to human health is mounting and so is the pressure on car markers to produce zero emission electric vehicles (EVs). The major bottle-neck for EVs is now battery management. New chemistries take time to develop so any improvement in efficiency in current techniques; lead, lithium, nickel, and sodium have to be exploited. Lithium Ion batteries require tight control of charge and discharge cycles and this requires individual monitoring of each cell [1]. EVs have around 300 cells connected in series and parallel and to monitor power in each cell requires each unit to be electrically isolated. Power transmission companies use Power Line Carrier Communication [2] where the line, voltage and current, are monitored via series capacitors and an imposed low frequency carrier is used to transmit the data to a remote station. A UHF based system using a similar techniques is investigated in section 2. The limitation to the directly coupled system prompted work on an electromagnetic coupled system described in section 3. The communication system for battery management was intended for a point to multipoint network with at least 300 cells connected.

2.0 Directly coupled transmission lines

A connection system consisting of 16 nodes directly coupled to lossy transmission line was simulated in Pspice [3]. In a practical system each node has cell parameters communicated by wireless low power transceivers based on the RFIC CC1101, from Texas Instruments. The maximum sensitivity these devices operate with 1% error was -112dBm. This was taken as the minimum signal level at any coupled node. Each node was assumed to be matched to 50 Ω.

2.1 Model

The SPICE model was constructed of 16 units each terminated by 50 Ω connected in a ring formed by coax connection using RG316 cable,. The cable was modelled by 0.12 m lossy transmission line with per unit distributed components shown in fig 1

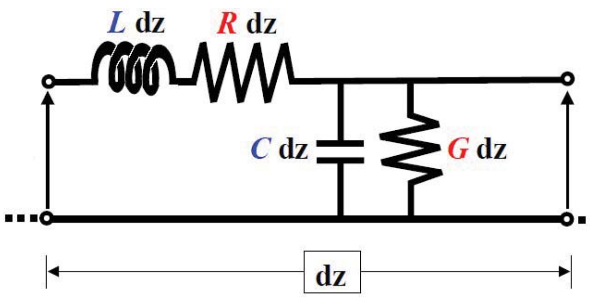


Figure 1 Unit inductance, L capacitance between core and screen, C insulation resistance G and series core resistance R over a per unit length dZ

Values of the distributed elements were set to : ΔL = 0.216uH, ΔR = 3.02 Ω,Δ C = 94.6pF ΔG = 9 uS. The velocity factor of this cable was specified as 0.66 c, where c is the velocity of electromagnetic propagation in a vacuum, so the electrical wavelength is shorter by this amount.

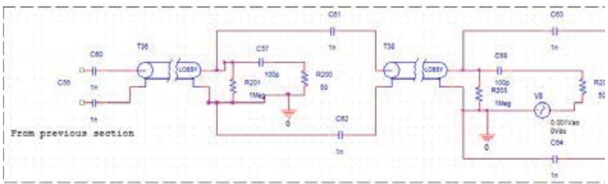


Figure 2 Two sections of SPICE model. Electrical isolation is provided by CC60- C64. The section on the left has a passive load of 50Ω and on the right a simulated source, V8.

Figure 2 shows the schematic of two sections of the model. It models all components seen in a practical design. Electrical isolation is required for each battery cell so each node is terminated by 50 Ω and electrically isolated by 1nF capacitors. It should be noted that these capacitances were modelled as perfect , but in practice commercially available ceramic capacitors with a breakdown voltage of 1000V would have a self-resonance close the working frequency of 900MHz. Even a low Q this would significantly attenuate the signal.

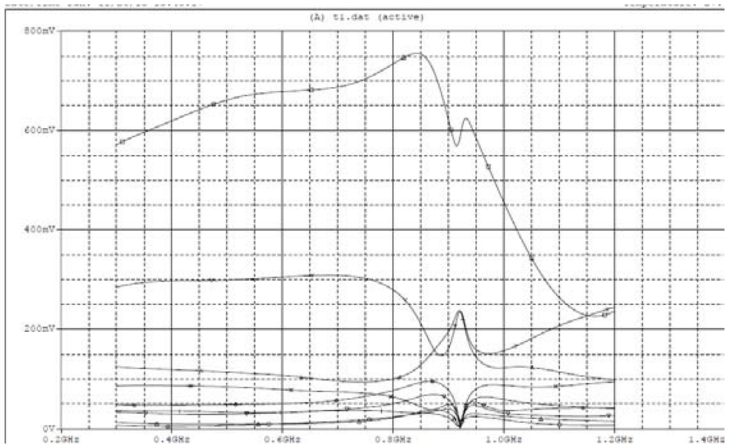


Figure 3 Signal voltage from 300MHz to 1.2GHz for eight positions around the ring. The nadir of the bottom 5 traces is around the required working frequency of 915 MHz

The results were more complex than expected with the ring configuration exhibiting a combination of band stop and pass filter response close to the working frequency, figure 3. The response is due to the reflections caused by the mismatched impedance between the 50 Ω cable and the nodes. In so doing reflections from each section will occur that combined destructively (band stop) and constructively (band pass) at specific frequencies. With the lengths of coax modelled this turns out to be around the working frequency of 900MHz and increasing the loop length lowered this frequency and thus response will be loop size dependent.

The worst attenuation seen by the ring connection of 16 units was 54dB which implies that connecting a ring of more than 32 cells would attenuate the signal below the input sensitivity of the CC1101. Breaking the ring into a single transmission line gives attenuation of 29dB, so the CC1101 would reach its sensitivity limit with more than 64 cells connected in line . If the termination was made with just one sink and one source then the attenuation over 16 units was 16dB. This would require , however, adding isolation switches to each unit and the protocol would be confined to point to point communication.

3.0 Electromagnetic coupled system

This section investigates an alternative connection method based on a partially radiating transmission line, but uses the same wireless transceiver CC1101. Since this was now a free-space (in air) radiating system, albeit in the near field, full-wave electromagnetic model was developed in in HFSS Ver 15 [5]. A full-wave simulation of 9 units were coupled to a single track of a 0.5m length of micro-strip transmission line. Memory availability and simulation time limited the model to 9 units.

3.1 Approach

Each transceiver node coupled in the near-field with this open , on one face, microstrip line. The coupling antenna from transceiver to the microstrip comprised of square loop, figure 4, ~0.16 λ_0 in size, where λ_0 is the free space wavelength at 900MHz.

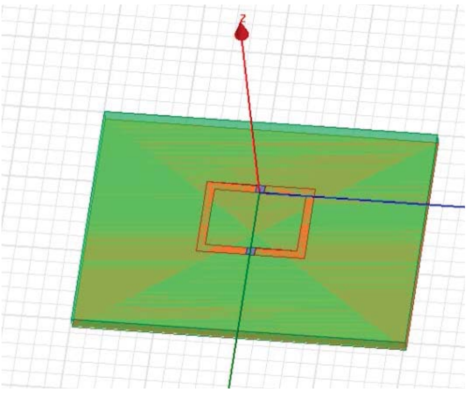
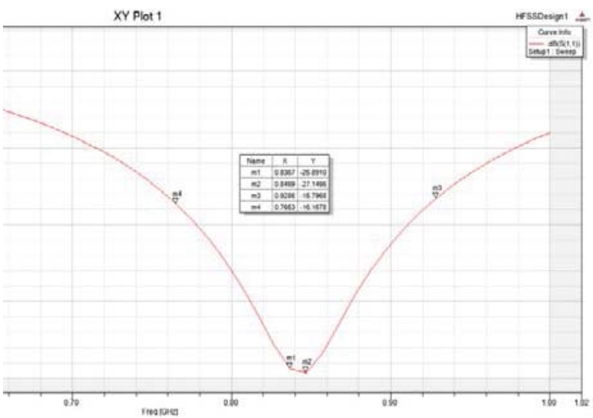


Figure 4 Loop is 13 X 10mm, 1mm wide



The loop in figure 4 has an access port that would be connected to the transceiver and a port on the opposite side loaded with a parallel combination of lumped capacitance, inductance and resistance respectively 4.5pF,

Figure 5 Return loss of loop Vertical in dB, horizontal in frequency. The -10dB return loss bandwidth was 300MHz. Lowest return loss was -27dB at 850MHz

9,5nH to resonate at 900MHz and 100 Ω to widen its bandwidth. The access port was connected to a source of the same output impedance of the CC1101 of 86 +j43 Ω. The return loss, with loop radiating into free space, is shown in figure 5. The -10dB bandwidth, representing a VSWR of 2, was 300MHz. So the loop would cover both 868 and 915MHz bands.

Nine of these loops were positioned under the transmission line separated by 10mm of air, figure 6.

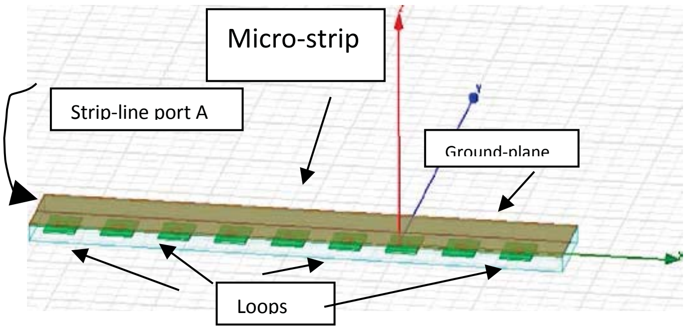


Figure 6 Micro-strip with loops configuration. Total length of the micro-strip is 515mm by 80mm wide

Each unit represents the electrical equivalent of the CC1101 transceiver and consists of a loop with a structure identical to that shown in figure 4 attached to sub board 30 X 40mm size and backed by a ground plane. This plane would be local ground to each unit but electrically (dc wise) isolated from each other. As before the loop access port impedance was equivalent to the transceiver unit output port i.e. 86 +j43 Ω . The units were separated by 55mm with adjacent board edges by 25mm. The linear micro-strip width was calculated to give a characteristic impedance of 50 Ω. The substrate for the micro-strip and loops was standard FR4 glass/epoxy mix and the track modelled as 35um thick copper.

3.2 Results.

The return loss at the drive port A is shown in figure 7

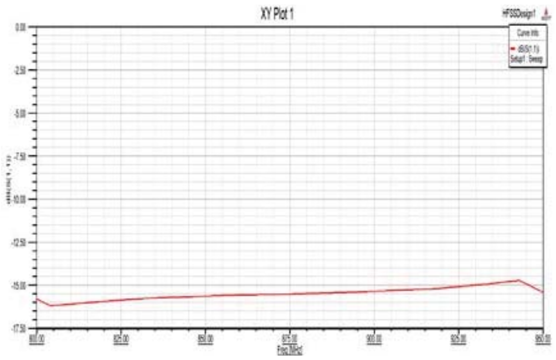


Figure 7 S11 at port A with the loops present - flat from 500MHz to 1GHz at -16dB

It will be noticed that the return loss is flat at ~-16dB for the entire band so little evidence of interference from the loops.

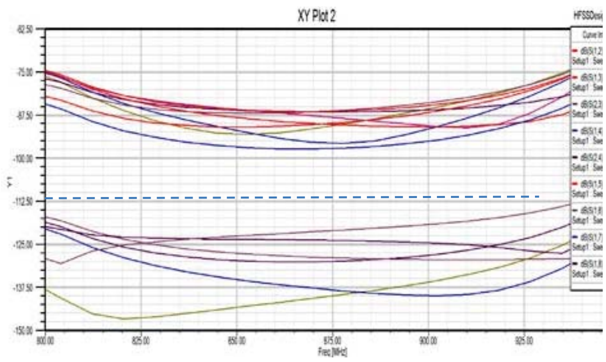


Figure 8 Top set of curves represents the attenuation between the loop port and the strip-line port for all nine loops. The bottom set of curves represents the loop to loop coupling. Vertical axis is in dB and horizontal axis is frequency spanning 500MHz to 950 MHz. The blue dashed line represents -112.5dBm

Figure 8 details the coupling between each loop and the transmission line ranging over -98 to -86dB at 868MHz. This is well within the dynamic range of the CC1101. The bottom set of curves in figure 8 are the loop to loop couplings between adjacent boards. At this separation it can be are seen they are all below the sensitivity of the CC1101 of -112dBm.

Compared with the directly coupled system this represents a vast improvement in performance. It implies that there is minimal interaction between the loop and transmission line, yet sufficient coupling to allow reliable communication. Coupling, which is in the near field at this frequency and separation, occurs mainly from the loop arms parallel to the micro-strip which would imply that the loop could be narrowed and still maintain the dipole coupling to the transmission line. Its port impedance would change but can be tuned to the required frequency changing the load impedance. This experiment was done with air as the separating dielectric. Ten millimetres gives a DC isolation of 3kV .

3.3 Electromagnetic coupling – measurement

Six open micro-strip transmission lines where connected in series terminated at one end with 50 Ω. Figure 9. On Each transmission line 22 nodules were mounted either as loads equivalent to the transceiver port or as an antenna connection which included a balun to allow for 2 port measurement with a vector network analyser. Each loop was plane parallel to the transmission line separated by 3mm of ABS plastic. The loop had the same

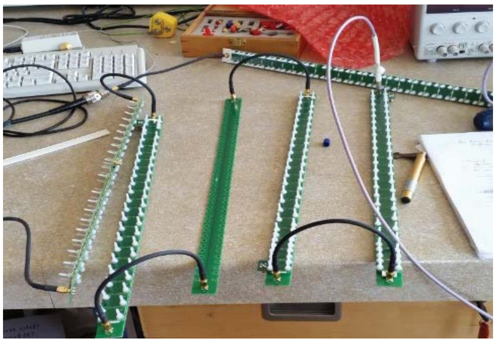


Figure 9 Six radiating micro-strip lines each connected with a 50 ohm coax cable

dimensions and loading as used in the simulation, gave the S11 response shown in figure 10

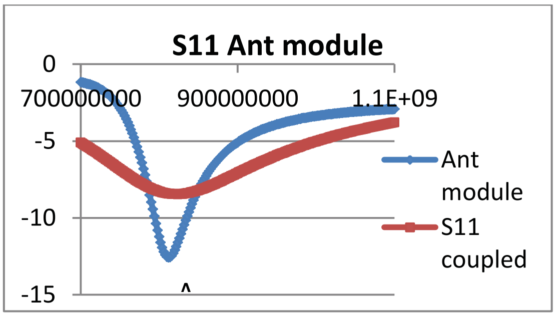


Figure 10 Measured S11 of uncoupled loop blue and coupled loop brown. Point A is ~800MHz

Overall the transmission line exhibited ~10dB attenuation over 6 units. At each coupling point along the transmission line the couple transmission coefficient, S21 was measured over a frequency range from 700MHz to 1.1GHz, figure 10

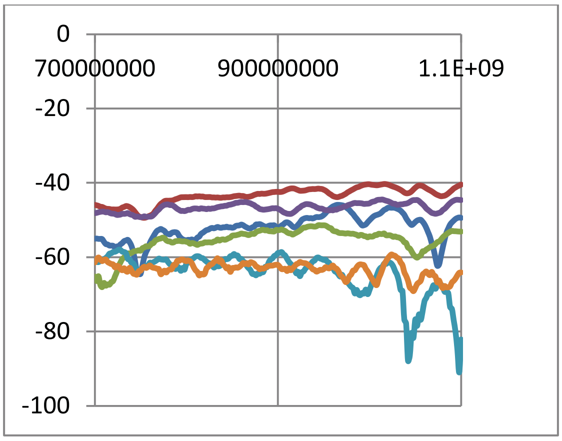


Figure 11 S21s of 6 coupled units, 1, blue curve was proximal to the source, 6, orange curve, was the most distal and nearest to the termination. Frequency straddles 700MHz to 1.1GHz. Each unit was coupled plane parallel to the TL via 3mm ABS plastic

Figure 11 shows the change in coupling strength with plane parallel distance of the antenna unit along the transmission line.

4.0 Discussion

First point to note is that the micro-strip transmission exhibited a characteristic impedance of around 39 Ω so was not well matched to the 50 ohm source. Second : the loop resonance peak (nadir in S11, figure 10) was centred too low for the required band between 850 and 920MHz, however it is notable that the resonance was flattened out when coupled to the micro-strip line, figure 10. This suggests the line presence loaded the loop more significantly than was estimated by simulation. The third point to note was that the couple, S21, attenuation was a good 20dB higher than in than the simulation primarily because the loops were coupled by a 3mm plastic spacer whereas the simulation had a 10mm air gap between the loop and line.

4.1 Theoretical Limits to weak field coupling

The scenario proposed was a waveguide or micro-strip with restricted radiation coupled weakly to sub-wavelength antenna. As the coupling weakens, the limit here is not the number devices but the signal to noise ratio of the active coupled device. However it is the reflection that the limits the number devices as the coupling strengthens.

The reflection for a loaded network stated in terms of scattering parameters is define thus;

$$\rho_{in} = S_{11} + \frac{S_{12}S_{21}}{1 - S_{22}\rho_l}\rho_l$$

Where ρ_{in} is the reflection seen at the source and ρ_l is the reflection seen at the load. S11 is the return loss and S12 = S21 (the system is assumed linear and therefore coupling is symmetrical) and S22 is the return loss at the remote unit. For N devices coupled weakly, in this application < 40dB, the total reflection seen at the source is the sum of the second term in the above equation for all nodes. The reflection in terms of VSWR limits the number of devices for a given coupling. VSWR was determined by$(1 + S11)/(1 - S11)$ and ρ_l was set to 0.33 (that is SWR equivalent to 2), figure 11

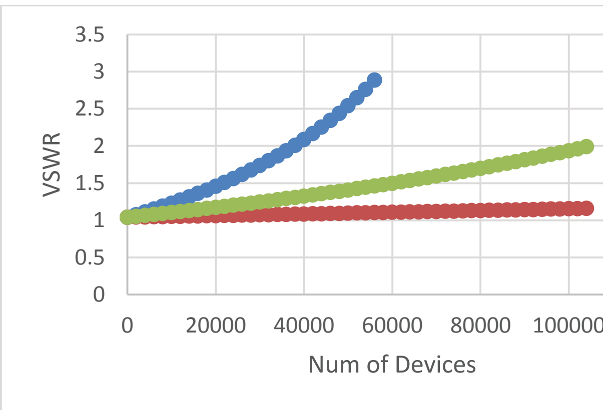


Figure 12 VSWR vs number devices brown -60dB, green - 50dB, blue - 40dB

5.0 Conclusion

The technique of weak coupling many units to one bus was shown to be feasible and could be extended to much larger busses with many more units coupled. If the output power from the interrogator unit is set to 10dBm and if on average each unit absorbs -70dBm of power the one bus could theoretically supply up to 10000 units . Potentially this technique has many applications where large numbers of devices need communication for sensing and actuation but have to be electrically isolated. It is analogous to a well-controlled broadcasting service where communication is half-duplex or a highly localised sensor network. This is now subject to a patent application [6]

The author wish to Acknowledge the support of Dukosi ltd : www.dukosi.com

References

1. Review of battery technologies for automotive applications. Published by Eurobat.org url : https://eurobat.org/sites/default/files/rev_of_battery_executive_web_1.pdf (12/12/16)
2. PLCC – power line carrier communication see http://electrical-engineering-portal.com/power-line-carrier-communication-plcc (12/12/16)
3. Cadence Pspice 16.3 http://www.orcad.com/
4. CC1101 http://www.ti.com/product/cc1101?keyMatch=CC1101&tisearch=Search-EN-Everything
5. HFSS ver 15 http://www.ansys.com/Products/Electronics/ANSYS-HFSS
6. Electric Batteries (2016) GB 1611532.1
7. Marc Heddebaut (2009) Leaky Waveguide for Train-to-Wayside Communication-Based Train Control. "IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 58, NO. 3, pp1068 - 1076