

TECHNICAL REPORT: CVEL-07-002

INVESTIGATION OF AM RADIO INTERFERENCE IN A TRACTOR

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EXECUTIVE SUMMARY

This report describes and evaluates an electromagnetic interference (EMI) problem in a tractor. Electrical noise on the power distribution bus in the tractor couples to an AM radio in the cab. The noise takes two forms. Switching transients on the power bus are heard as “clicks” in the speakers and harmonics of power inverter transients can be heard as “tones” with frequencies of a few kHz.

Systematic measurements demonstrate that the primary coupling mechanism between the power bus and the radio is conducted noise entering through the two radio power inputs. A secondary field-coupling mechanism is also capable of producing significant audible noise in the speakers. Filter capacitors on the power inputs significantly attenuate the conducted interference. A ground plane at the base of the antenna essentially eliminates the field-coupled interference.

One recommendation for fixing this problem on existing tractors is to filter the two radio power inputs and keep any unfiltered power wiring away from the radio and the base of the antenna. Another solution for eliminating the troublesome “tone” interference (both conducted and field-coupled) would be to filter the power inverters that are putting the transients on the power bus.

I. INTRODUCTION

The AM radio receiver in a tractor provided for this study exhibited significant electromagnetic interference (EMI). The objective of this project was to investigate the sources and coupling paths associated with this interference. The first step in this investigation was to listen to the radio tuned to various channels while powering different electronic systems in the vehicle on and off.

The most notable interference observed was in the form of audible “clicks” or “tones”. The type of interference and the magnitude of this noise varied depending on the AM channel selected. Time and frequency domain measurements of the speaker terminal voltage and power bus input voltage were made to quantify this noise. Experiments were then performed to identify various noise sources and coupling paths.

II. SUBJECTIVE AUDIO TESTS

Subjective audio testing was performed at the beginning of the investigation to determine which sources of interference were most significant. For these tests, the ignition switch was turned to the ON position and the AM radio was also turned on. In-vehicle electronic devices were operated one by one with the radio tuned to selected frequencies between 530 kHz and 1710 kHz. Local radio stations were received on two of the twelve stations settings. The remaining settings were relatively free of any intentional transmissions. Devices found to generate significant noise included the hazard lights, the left turn light, the right turn light, the air conditioner, and the dome light. Other devices, such as the windshield wipers, brake pedal, gas pedal, and gear shift also generated noise, but at a lower level compared to the ambient noise in the cabin while operating these devices. The volume setting of the radio receiver was set to “11” during these tests. Table 1 summarizes the results of the subjective audio tests. In this table, “A” indicates strong interference that could be heard clearly and continuously; “B” indicates weak interference that could still be heard; “B+” indicates the interference was stronger than “B” but weaker than “A”; “C” indicates the interfering noise was only heard at the moment the device was turned on; “O” indicates the interfering noise could not be heard. Transient “clicks” generated by the hazard lights was the most obvious interference. Additionally, “Buzz Noise”, or 2 kHz - 5 kHz tones could be heard at nearly all AM radio station settings. These low frequency tones were perhaps the most irritating of all the electronic interference. The tones varied in frequency and amplitude depending on the station selected and the state of the battery among other things. The tones were usually unnoticeable when the engine had been turned off for a long time and got stronger when the engine had been on for a while.

Table 1. Results of subjective audio tests

AM Station	Hazard Lights	Right Turn Light	Left Turn Light	Air Conditioner	Bulb Inside	Buzz Noise
530	A	B	B	C	C	A
600	O	O	O	O	O	A
700	A	B	B	C	C	A
800*	O	O	O	O	O	A
900	A	B+	B+	C	C	A
990	A	B+	B+	O	C	A
1090	A	B+	B+	C	C	A
1200	A	B	B	C	C	A
1330*	A	B	B	C	C	A
1490	A	B	B	C	C	A
1610	A	B	B	C	C	A
1710	A	B	B	C	C	A

* AM station settings with good local radio station reception

III. COUPLING PATH INVESTIGATION

Based on the audio tests, it was apparent that power bus noise was being coupled to the radio. There were only two[†] possible coupling paths that were consistent with our observations at this point.

1. Noise could be conducted into the radio on the power inputs.
2. Noise could be field-coupled from the power wiring to the radio antenna.

In order to evaluate these possibilities, selected electronic devices were turned on one by one and the voltage on the wiring supplying power to the radio and/or the voltage at the speaker terminals were measured in each of the following four configurations:

Original Configuration – voltage on the input power to the radio and the speaker terminals were measured without changing anything;

Resistor Configuration – the radio was replaced by an equivalent resistor and the voltage across this resistor was measured;

External Power Configuration – same as configuration above, but radio was now powered by an external power supply;

External Power with Ground Connection Restored – same as configuration above, but power bus ground was reconnected.

[†] It was also possible that noise was field-coupled directly from the power bus wiring to the speaker wiring, but this unlikely scenario was ruled out by making a few simple measurements early in this investigation.

Fig. 1 through Fig. 7 show the measured voltages at the power input of the radio and/or the voltage on the speaker terminals in these four configurations. For these measurements, the AM channel frequency was set to 900 kHz and volume level was 6. Fig. 1 and Fig. 2 show the measured voltages across the radio power input and speaker terminals, respectively, in the original configuration. In Fig. 1, it is evident that when the hazard lights, the right turn light, or the left turn light are turned on, voltage spikes appear on the power input that coincide with the lamp switching events. Similar interference can be observed in the signals to the speaker as shown in Fig. 2. The interference generated by operations of the right and left turn lights are not evident in the measured signals, even though the noise was audible.

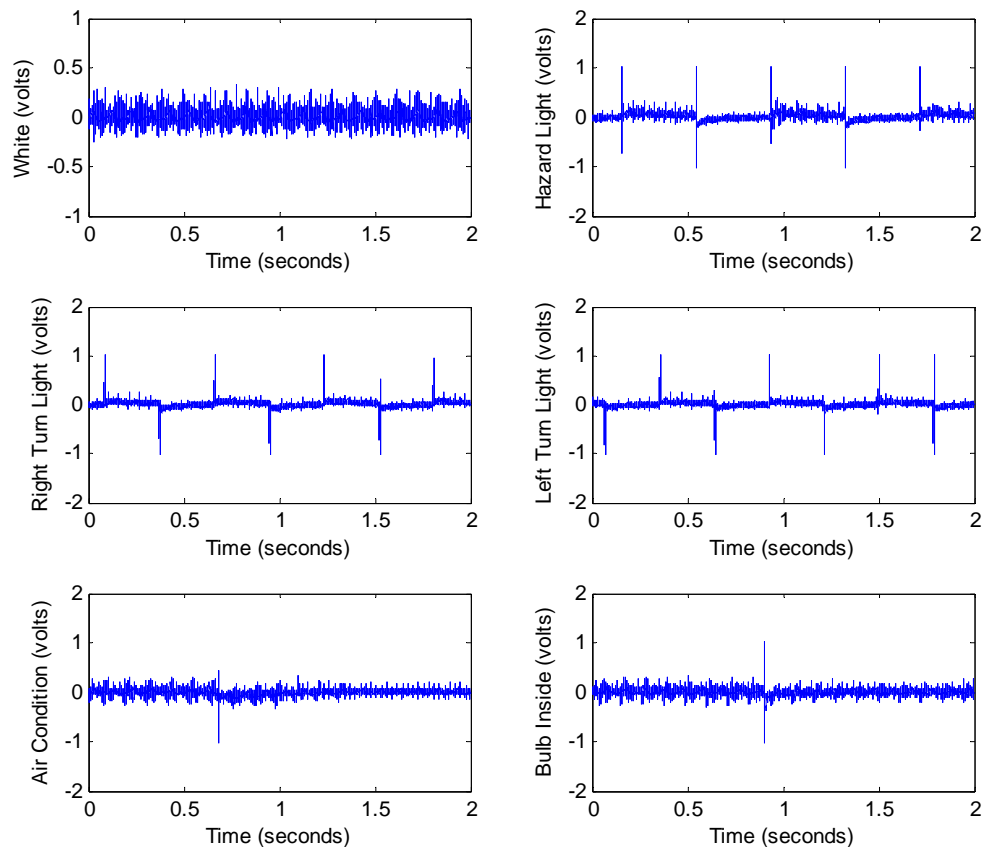


Fig. 1. Voltage on power input with various devices activated.

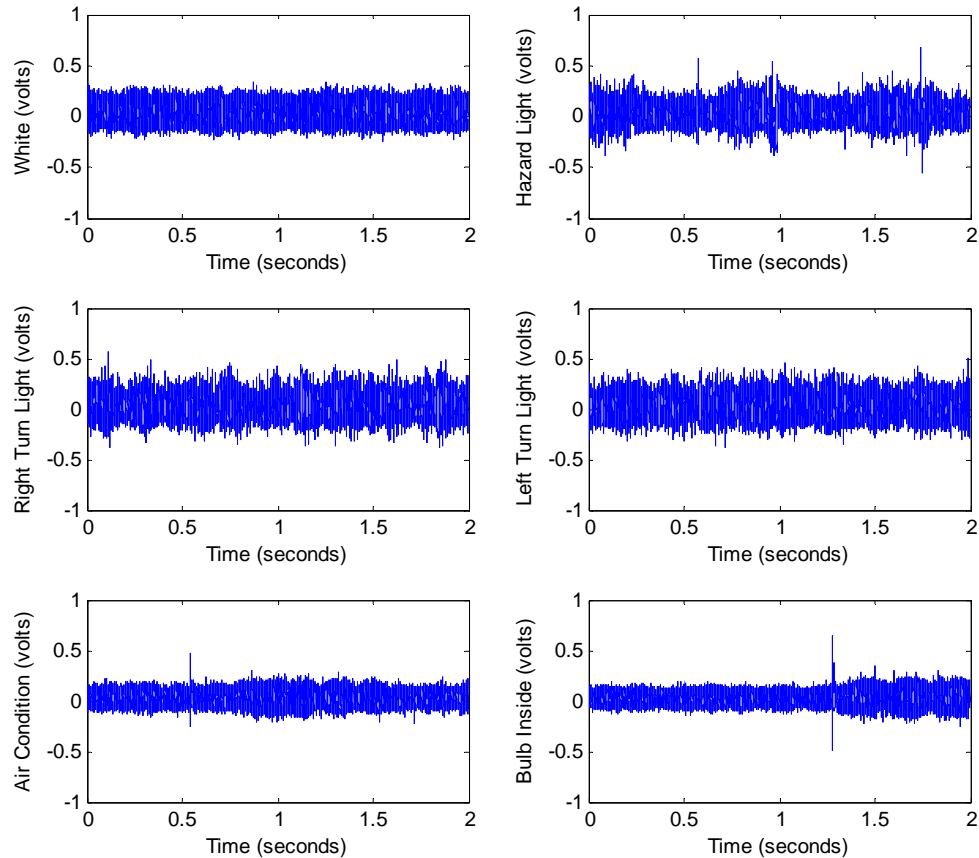


Fig. 2. Voltage on speaker terminals with various devices activated.

The voltages dropped across an equivalent resistor with original battery power are shown in Fig. 3. In this configuration, the impact of different operations on the input power is similar to the impact in the first configuration. In other words, the transients appeared on the power wiring whether or not the radio was connected to the power wiring.

Fig. 4 and Fig. 5 show the measured voltage on the power input and speaker terminals, respectively, in the External Power Configuration. In this configuration (note the change in vertical scale), there is no measurable interference on the radio's power input and no transient noise on the speaker wiring. During the measurements in this configuration, a weak interfering tone noise could still be heard in the speakers when the engine had been on for a while.

When the power bus ground wire is reconnected, there is a slight change in the voltage on the speaker terminals as shown in Fig. 6. In this configuration, the transient noise is once again audible (though barely). This is indicative of field coupling, since there is still no conducted path to couple the power bus noise to the radio.

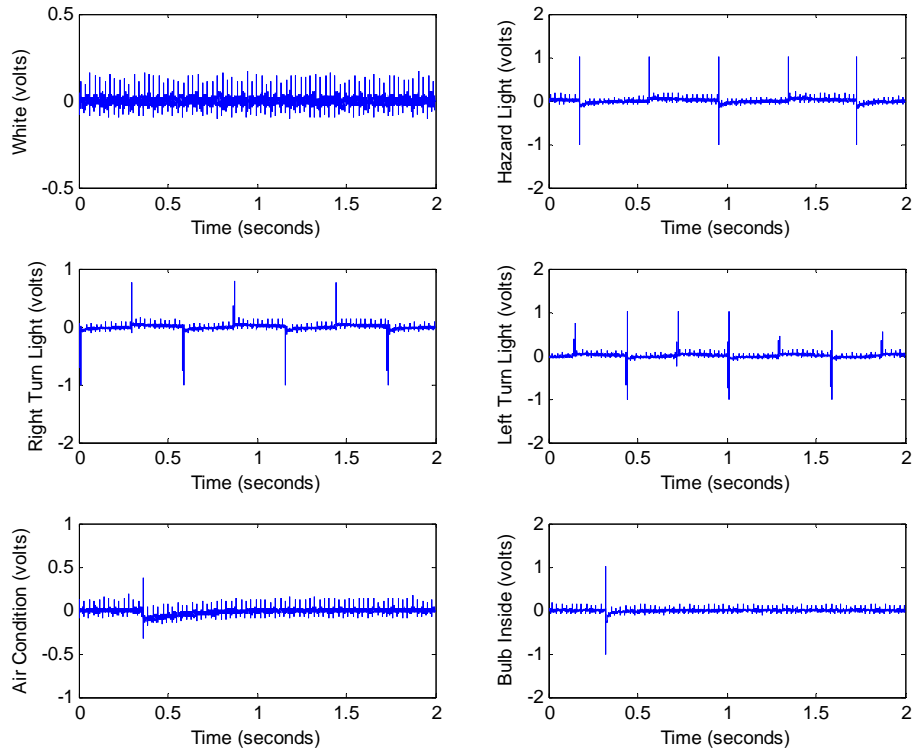


Fig. 3. Voltage across the resistor, when the resistor replaces the radio power input.

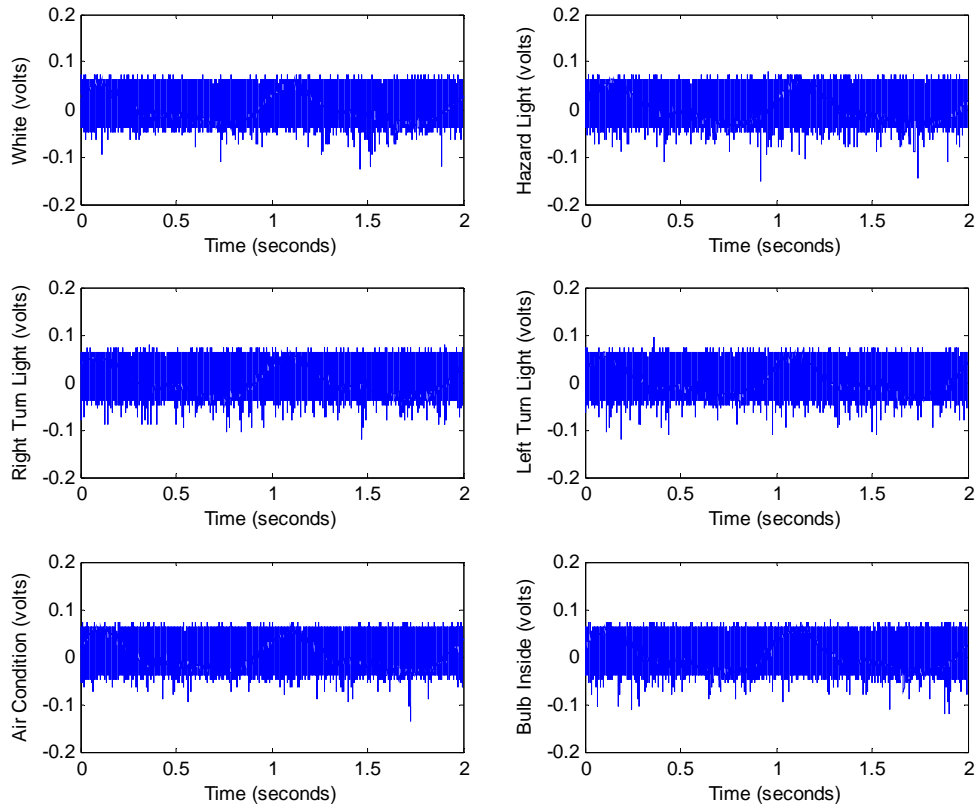


Fig. 4. Voltage on the radio power input, when power is supplied by an external supply.

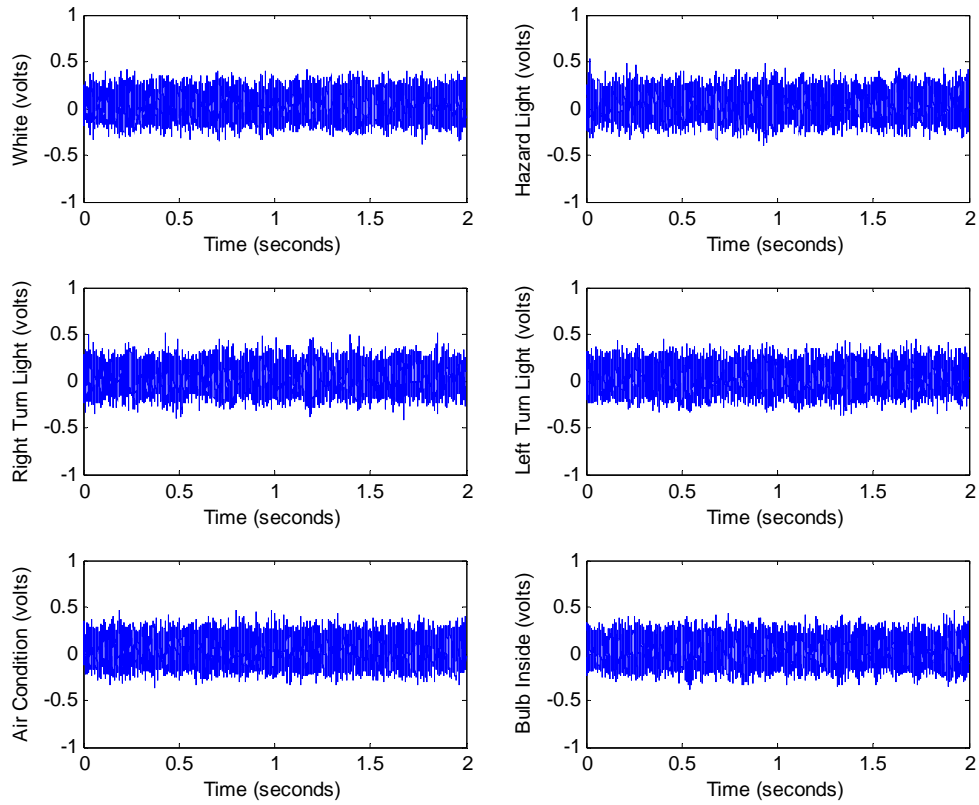


Fig. 5. Voltage on speaker terminals with an external power supply.

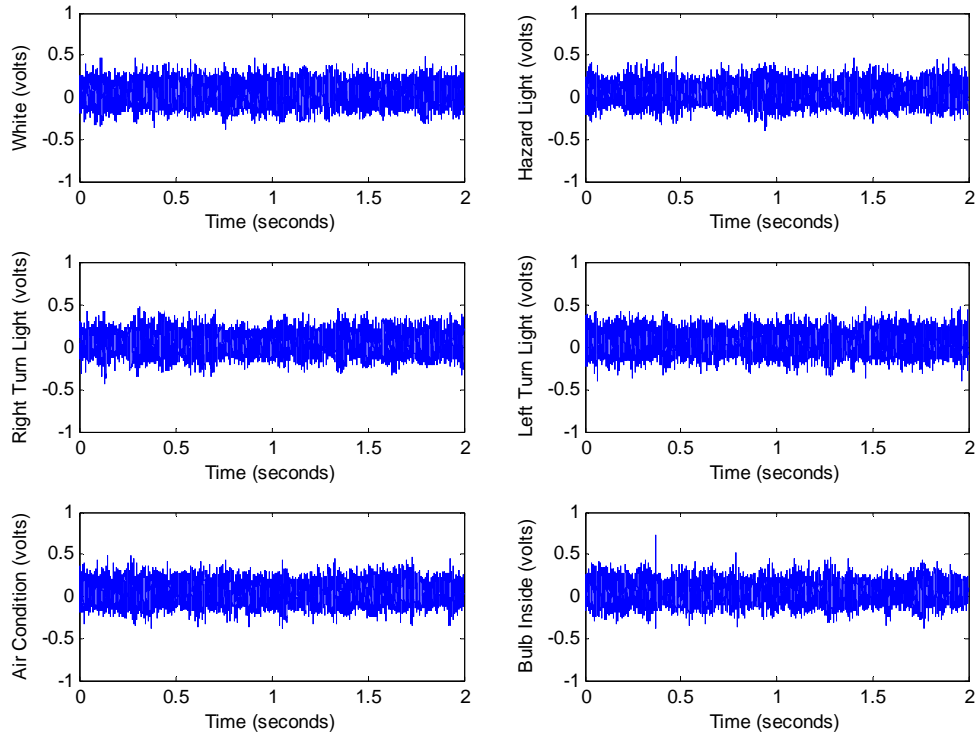


Fig. 6. Voltage on speaker terminals with an external power supply (ground wire reconnected).

IV. ADDITIONAL MEASUREMENTS & ANALYSIS

As stated in the previous section, a little power bus noise can be heard on the speakers even when an external power supply provides power to the radio. This is due to electric field coupling between the power wiring and the AM radio antenna. Examination of the antenna mounting position showed that the “monopole” antenna did not have a ground plane. The antenna was mounted on a non-conducting surface. This effectively turned it into a “dipole” antenna where the chassis metal and “ground” wires in the vehicle served as the other “pole”. This means that noise currents flowing in the chassis and on the power wiring near the base of the antenna are readily coupled to the antenna input of the radio.

A large piece of aluminum foil, used as a ground plane, was connected to the base of the antenna. The ground plane was not electrically connected to any other part of the chassis. This restored the “monopole” and blocked electric field coupling between the antenna and the power wiring near the base of the antenna. At the same time[‡], a 10- μ F capacitor was placed on each of the power inputs to the radio significantly attenuating the conducted noise on the power wiring.

[‡] Capacitors on both power inputs were required to eliminate the conducted interference. A capacitor on the main power alone was not effective.

Fig. 7 shows the measured voltage dropped across the radio receiver. In this figure, part (a) corresponds to the original configuration, part (b) shows the effect of applying the filter capacitors, and part (c) shows the effect of adding both filters and a ground plane. It is evident that voltage spikes on the power are significantly attenuated by the capacitors. The ground plane has very little effect on the measured power bus noise, but it prevents this noise from coupling into the radio via the antenna input. Audible interference from the power bus was eliminated by the combination of filters and ground plane.

In this case, the ground plane was used to demonstrate that electric field coupling was responsible for some of the audible noise coupled to the radio. We do not recommend using a ground plane to fix this problem on production tractors. A better approach would be to route power wiring in the tractor in a manner that prevents high frequency power currents from flowing in the chassis and cabling in the vicinity of the base of the antenna.

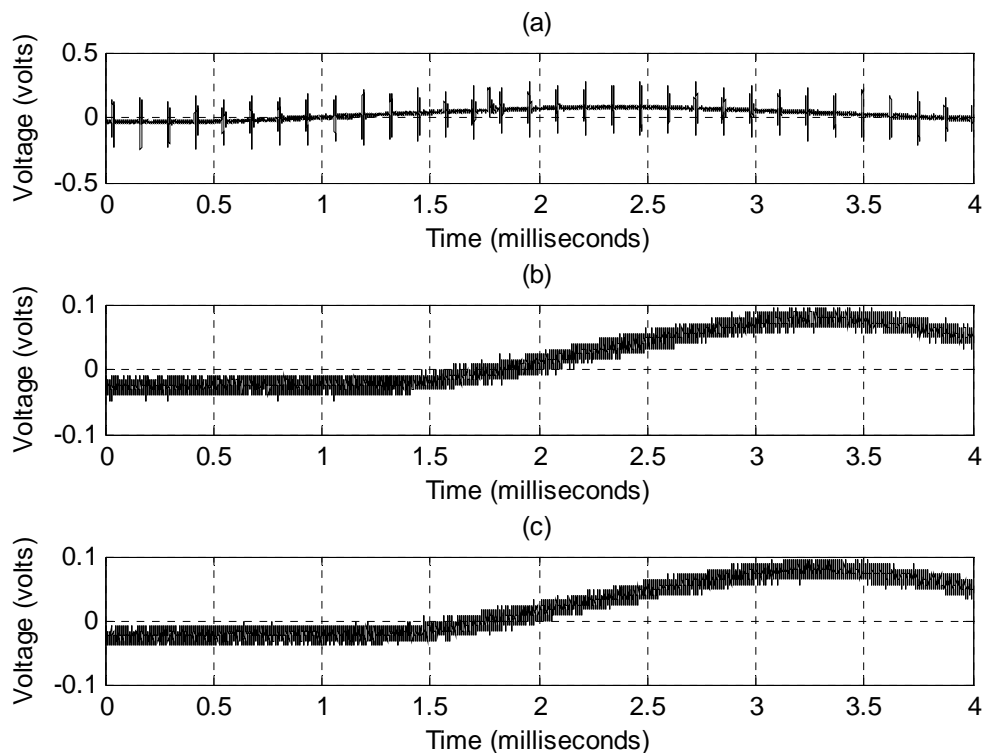


Fig. 7. Voltage on radio power input in different configurations (a) original; (b) filters applied; (c) filters and ground plane applied.

The 4-millisecond time scale in Fig. 7 is useful for illustrating that spikes occurred on the power bus wiring every 120 μ s or so. These are apparently due to one or more power inverters somewhere in the tractor. The amplitude and frequency of these spikes varied depending on the

battery state and number of electrical loads activated in the vehicle. This waveform appeared to be responsible for the steady “tones” heard in the speaker.

Fig. 8 (a) illustrates the measured voltage on the power bus over a longer time period than Fig. 7. With this time scale, we observe another peaking noise source with a period of about 8 ms. Fig. 8 (b) shows the corresponding frequency domain data. A peak at around 7.8 kHz corresponds to the period of the spikes in Fig. 7 (a). The plot also shows peaks at harmonics of 130 Hz corresponding to the 8 ms peaks in Fig. 8 (a).

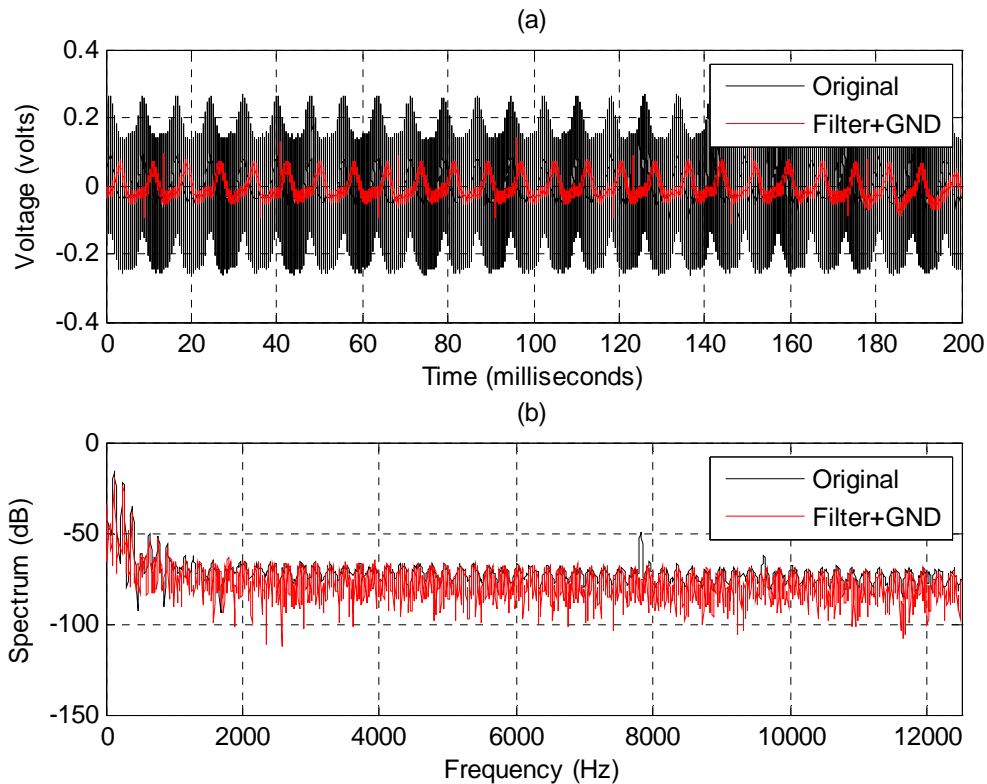


Fig. 8. Voltage on radio power input in (a) time domain and (b) frequency domain.

Figs. 9 - 13 depict the measured voltage on the speaker terminals at selected radio station settings from 530 kHz to 1710 kHz. These figures show that the dominant peaks between 1 kHz and 12 kHz, responsible for the annoying “tones” in the original configuration, are successfully suppressed when the two filter capacitors and a ground plane are applied.

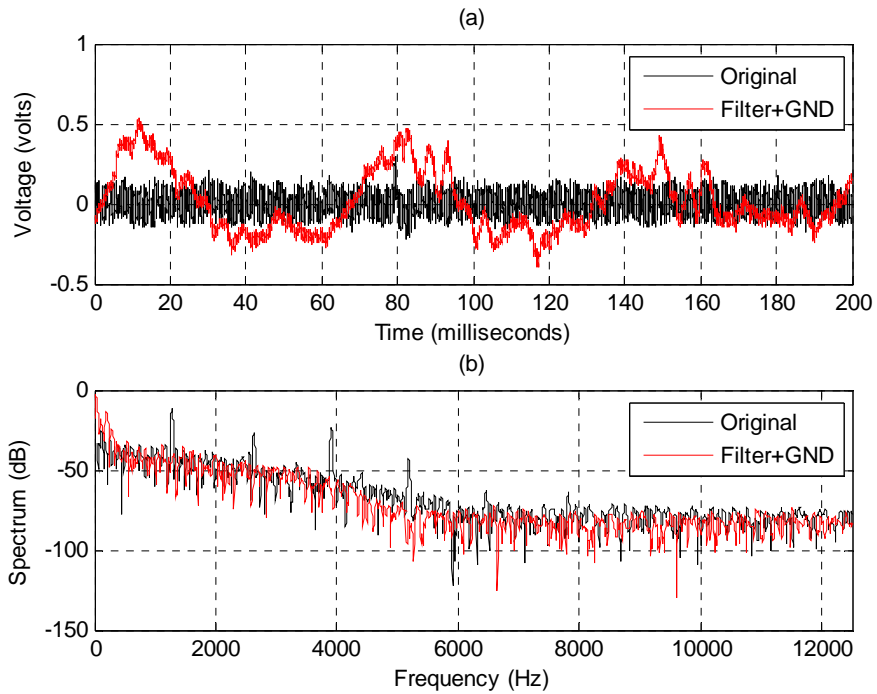


Fig. 9. Speaker voltage with radio set to AM 530 in time domain and frequency domain.

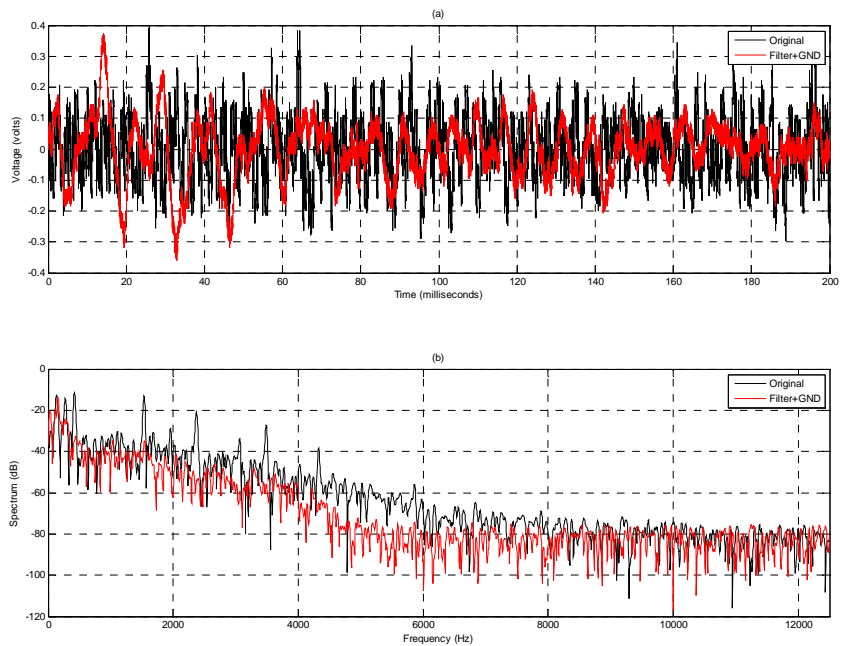


Fig. 10. Speaker voltage with radio set to AM 900 in time domain and frequency domain.

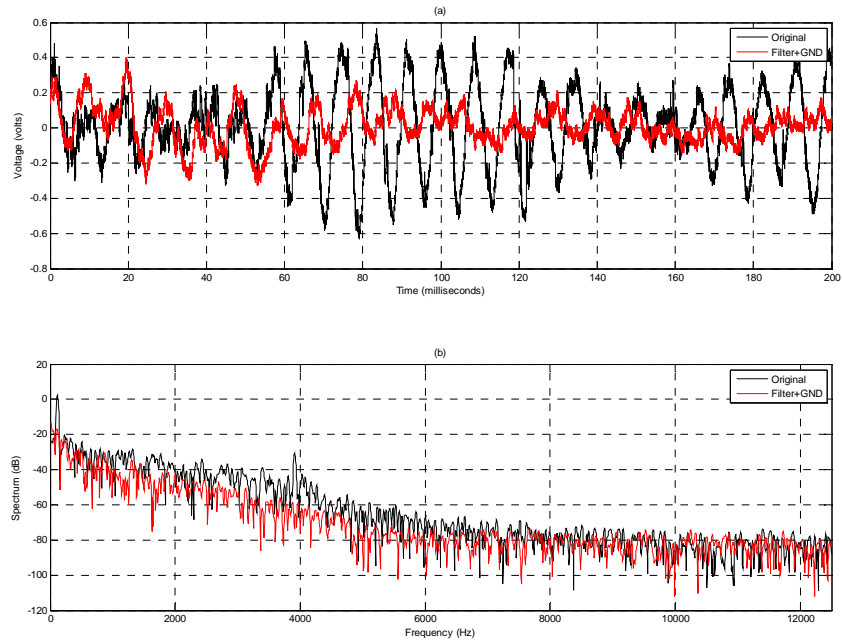


Fig. 11. Speaker voltage with radio set to AM 1090 in time domain and frequency domain.

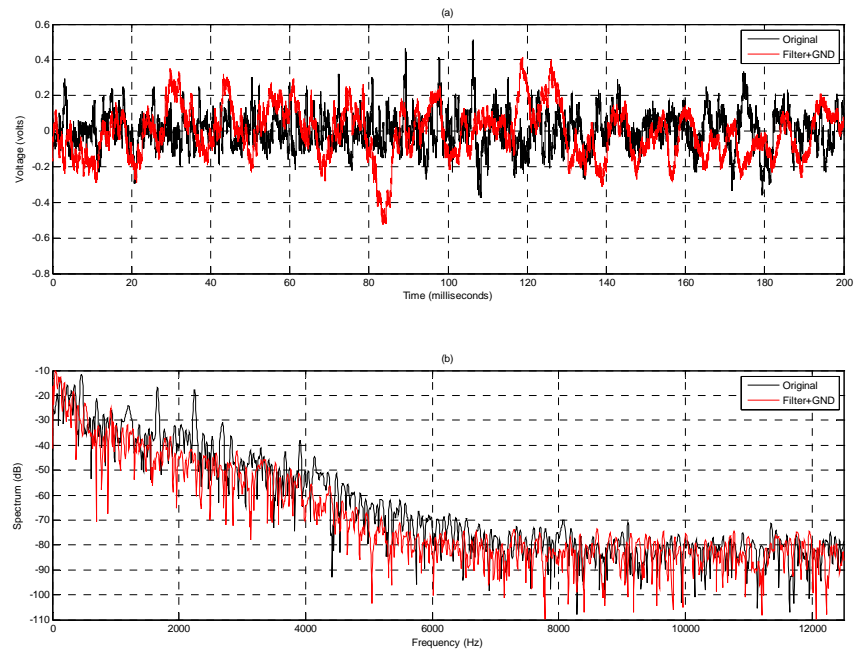


Fig. 12. Speaker voltage with radio set to AM 1490 in time domain and frequency domain.

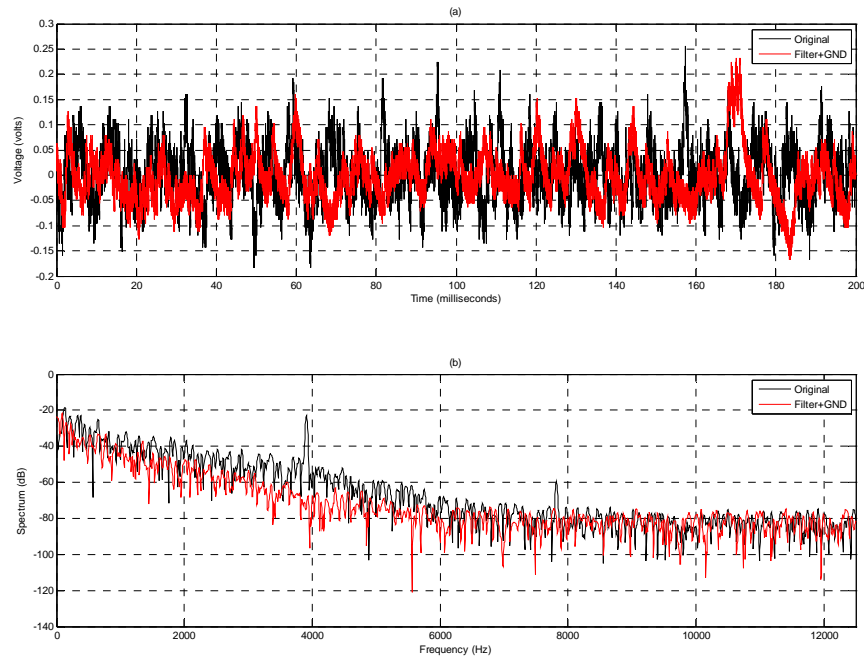


Fig. 13. Speaker voltage with radio set to AM 1710 in time domain and frequency domain.

VI. CONCLUSIONS

The results of the measurements conducted during this study show that the tractor's AM radio interference problems are caused primarily by conducted coupling of noise on the power bus wiring. Field coupling from the power wiring to the antenna contributed significantly as well, but field coupled noise could only be detected after the conducted noise was eliminated.

Filter capacitors can be applied to effectively reduce the conducted coupling. Field coupling can be attenuated by locating the antenna on a ground plane; or in the absence of a ground plane, by keeping any wiring with voltage transients (such as the unfiltered power bus wiring in this tractor) away from the chassis and cables connected to the base of the antenna.