Impact of Repair Joints in Fencing Wire on Data Communications: How to Receive Radio and Block Data using No. 8 Wire

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***Abstract*—Modern electric fences have remote controls and remote monitors that communicate with the energizer through the active fence wire. This manuscript looks at the impact of repair joints on the data communications between energizer and remotes. We report measurements of nonlinear rust-induced characteristics in joints and we draw conclusions about their effects in the context of an electric fence carrying data communications signals. We furthermore demonstrate how their nonlinear characteristics can cause mixing and detection effects that could account for radio reception.**

I. Introduction

Modern electric fence energizers offer the possibility of remote control and remote measurement of pulse voltage level. These energizers use the fence wire as the transmission medium for the data. The idea was first patented in 1993 [1], and a number of other patents appeared in the following decade [2]–[5]. The communication can be bi-directional, and is typically a low bit-rate FSK modulation operating at a few tens of kilohertz.

It is common for fence wire to be joined during repair or modification of the fence layout. After being exposed to the elements, a joint may develop an insulating layer. This is obviously known to have little effect upon the high tension pulses, but could the increased impedance of the joint be detrimental to the signal strength or signal integrity of the transmitted data sent between the pulses? This manuscript examines the characteristics of corroding joints and the impact of such joins on low-level signals travelling along the fence network.

No research could be found in the engineering literature on the electrical nature of faults that might occur in agricultural fencing.

In the early 20th century, mercury-arc rectifiers were the most efficient way to rectify alternating current into direct current for industrial applications [6]. This design is electrically robust and is capable of extremely high power rectification. Eventually these were superseded in a number of application areas by metal rectifiers based on selenium and copper oxide in the 1930's [7]. Metal rectifiers were able to handle high forward currents but tended to have low reverse voltages so a large number of junctions were required to increase breakdown level (inevitably increasing the resistance of the device). These devices were quickly superseded by semiconductor devices but are still available in small quantities and used for specialist applications. The lesson from these observations is that simple junctions of dissimilar metallic materials and their oxides can produce a conduction barrier.

Railway signalling engineers use the metal rails in conjunction with the wheels and chassis of a train to produce an electric circuit [8]. This circuit is used as a safety feature to detect the presence of trains on sections of track. The resistance of the circuit is measured by a circuit which triggers when the resistance drops below a preset value, indicating a train present on the track. This system is sensitive to any degradation of the track surface which increases the resistance of the circuit. Rust on rails is a known hazard. Ironically the risk from failure to detect a train by this means has been increasing in recent years as railway suspension systems and brakes reduce the punishment that wheels meet out to rails, as rust forms a good insulator when compacted rather than scraped away. [8] This rust-based insulation suggests what may occur in poor joints on an electric fence. This could be expected to impede communications.

A dry joint can be thought of as conduction failure arising from failure to properly alloy metals at a junction, and typically consists of metals surfaces separated by a very thin insulating layer of undefined, insulative composition. The nonlinear effects of dry joints have been exploited to detect faults in buried cables [9]. It must be quite possible for a fence join to become a "dry" joint, as little or no attempt is typically made to connect the wires except by mechanical force.

The wireless base station industry has problems with intermodulation occurring in passive components, especially cables and antennas, with corrosion being supposed to possibly contribute, but investigations are usually limited to measuring and eliminating faulty components. The signal levels are typically quite low, even given decent RF power [10]. Passive intermodulation distortion (PIMD) is known to arise from a

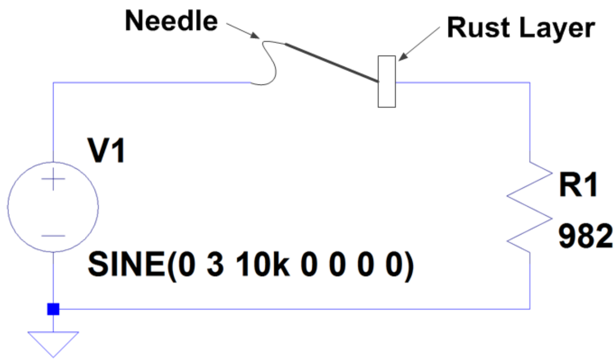

Fig. 1. Schematic of test circuit. A sinewave of 3 V peak at a frequency of 10kHz is shown (simulator notation).

Fig. 2. Photo showing experimental setup of Rust Joint

multitude of other reasons, though in RF transmitters it is chiefly attributed to thermal effects [11]. There are predictions of distortion arising from corrosion, but they are mathematical and not directly supported by measurements [12].

We report here some experiments on the properties of deteriorating fence joints. We disclose a novel theory that can explain demodulation of radio signals within an electric fence structure.

II. Characterising a Corroded Joint

Standard agricultural fencing wire is galvanised steel, 2.65mm in diameter, usually described as "number 8", short for number 8 gauge. A reef knot is the common configuration used to join two lengths of wire. When the joint is exposed to the elements, water ingress occurs and the joint corrodes. The zinc layer deteriorates first due to sacrificial galvanic corrosion, before the steel rusts, at which point an iron oxide layer forms in the joint. [13] Ultimately this layer will stop the joint from conducting. At specific thicknesses, the joint can exhibit non-linear impedance characteristics.

In order to investigate the impedance characteristics of rusty steel contact an arrangement resembling a "cat's whisker" was constructed with a rusty bar and a needle. The schematic diagram appears in figure 1, and a photograph of the setup appears in figure 2. A signal generator was used to produce sine and triangle waves at a frequency of 10 kHz with varying amplitudes. A Tektronix TBS1062 oscilloscope was used to sample the voltage and current waveforms. By dragging the needle across the rust layer and applying more or less pressure, the quality of the connection could be varied. Mostly the joint would appear either as an open or a short circuit. Nevertheless, the oscilloscope would sometimes display a distorted waveform when a certain rust layer thickness was achieved. This method is delicate and it could take a significant period of time to achieve a joint that was neither completely isolated nor fully conducting, but the outcome was repeatable.

Some measurements are presented in figure 3. Initially the nonlinear characteristic appeared with a source voltage of 3.3 V peak. The signal amplitude was then increased from 3.3 to 3.8 V. This increased the current through the junction and

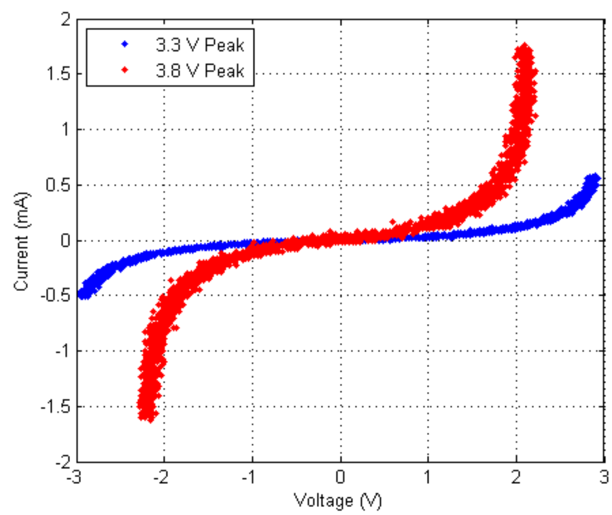

Fig. 3. Measured I-V characteristic of a rust layer demonstrating non-linear conductivity.

reduced the voltage drop as shown in the figure. Increasing the signal amplitude eventually resulted in the junction failing to a short circuit. Once the junction had failed to a short circuit, it would not return to its previous semi-conducting state and would need to be reconstructed by dragging the needle to a new location. We speculate that time would allow corrosion to re-establish a suitable isolation of the conductors, or more pragmatically that waiting an appropriate period of time will achieve whatever degree of isolation might be required.

III. Implications for Data Transmission

These findings have implications for data transmission using the active wire of an electrified fence. Fence line impedance is highly variable. The fence itself acts as a transmission line with a characteristic impedance of typically several hundred Ohms. [14] A fence can terminate in an open circuit, or may suffer significant "vegetation loading" through grass growing up or branches leaning down. The operator of a remote control unit appears as a load, and this load varies greatly with frequency. [15] Operator series impedance and fence characteristic impedance have been measured to change with circumstances such as weather, through its effect upon ground conductivity and operator clothing [16]. It is very difficult, even by design, to get a matched termination on a fence with low return loss [16].

A rusty joint can appear as a capacitor of about 30 picofarads. At frequencies typical of fence remote controls, this is effectively an open circuit. If the insulating layer is thin, it will be destroyed by the high-tension (HT) pulse, and the wires effectively welded together. Unfortunately, if a joint fails while the fence is off, there will be no pulses to clear the fault, and a remote control might be unable to restart the fence. The implication is that a remote should be able to develop a substantial voltage on typical fence loads. One remote studied[1] is capable of producing signal amplitudes in excess of 100 V at light loads. This is intended to be sufficient to cause a rusty junction to fail back to a conducting status.

It should be noted that a communications protocol based at a much higher frequency, where 30pF is a lower magnitude of reactance, would withstand even (dc) open-circuit joints. Similarly, a complex-modulation signal, even at high frequency, would suffer intermodulation interference in the presence of such a joint.

IV. Potential for Nonlinear Action of a Fence Joint

Observation of the highly nonlinear, albeit symmetrical, characteristic observed in figure 3 leads us to recall stories of radio reception in agricultural fencing and dental fillings. Could this be a source of the nonlinearity required for signal detection?

We propose a novel application of a corroded fence joint as an AM radio transmission demodulator. The component arrangement is depicted in figure 6. The fence joint is biased using two fencing staples, one galvanised, and the other perhaps only rusted steel. These have the potential to produce electrochemical cells when they connect with the fence wire. Each cell is supposed for our purposes to produce a different potential, giving a total biasing of, for exampe, 0.8V, which is considered quite typical. [13] This allows the fence joint to operate in the non-linear region to one side of the centre of the characteristic, where it has an exponential type of I-V characteristic. The RF picked up by a long stretch of fence acting as an antenna is passed through the joint and thence a low-pass filter, before supposedly being connected to an audio reproduction system, say a crystal ear piece. It should be noted that the nonlinear joints in this system would be exceedingly fragile and easily damaged, butthen they are firmly connected to solid posts. It would require a junction with a precisely-appropriate rust thickness to operate successfully.

In order to demonstrate the viability of this arrangement we simulate a model of it using SPICE. We model the fence joint as two silicon diodes, see figure 7. A 5 kHz sinusoidal waveform is impressed upon a 1 MHz carrier using Amplitude

1 A Gallagher iSeries Remote control.

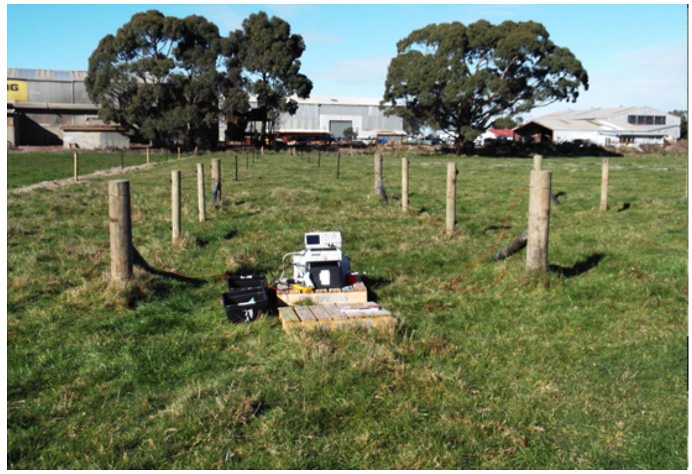

Fig. 4. The fence constructed for testing the impact of various components on the energizer communications system

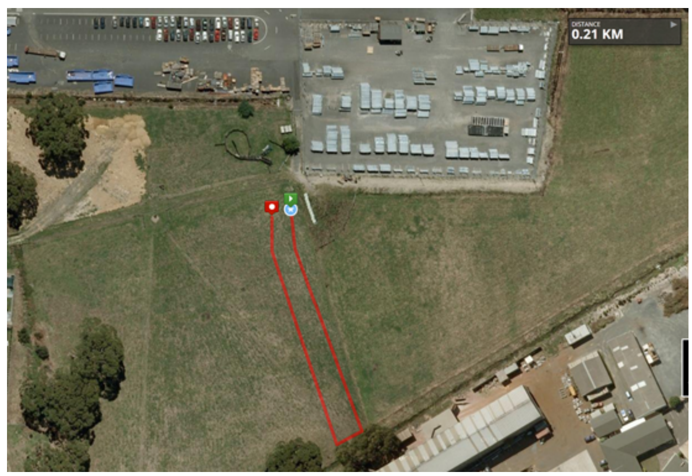

Fig. 5. A satellite map showing the layout of the test fence used for this research

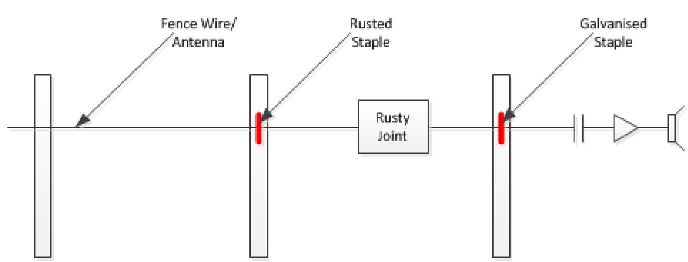

Fig. 6. The arrangement that is proposed for causing a corroded fence joint to demodulate AM radio transmissions. The rusty and galvanised staples produce a small dc potential to bias the rusty joint in order to achieve asymmetry in its characteristic.

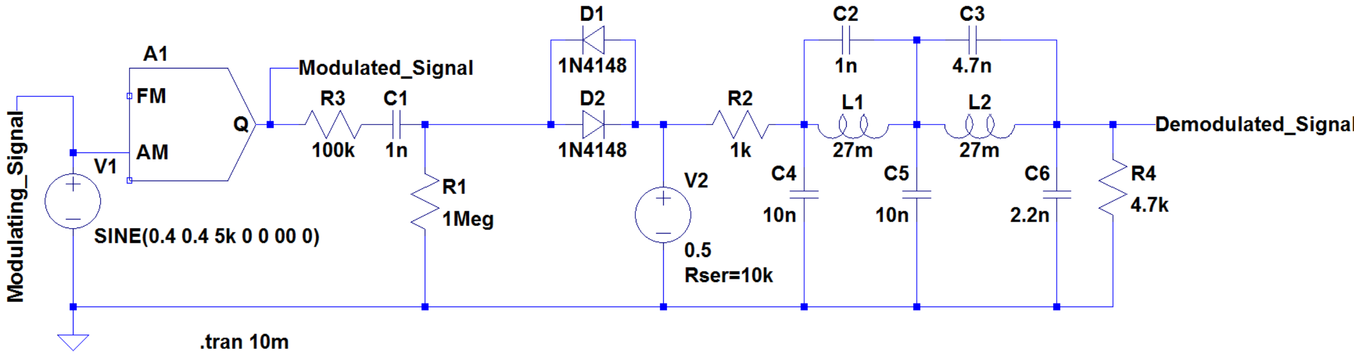

Fig. 7. Demodulator circuit as simulated in LTspice. A 5 kHz modulating signal is generated by V1 and modulated onto the 1 MHz carrier using A1. The filtered signal is measured across R4

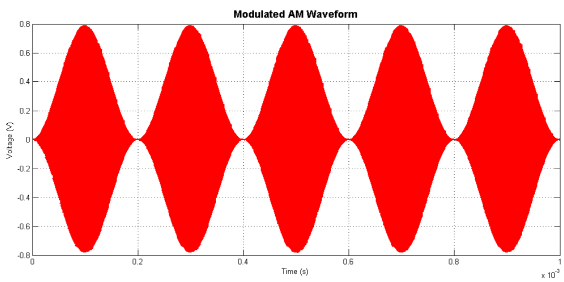

Fig. 8. The Amplitude Modulated (AM) waveform collected by the fence acting as an antenna.

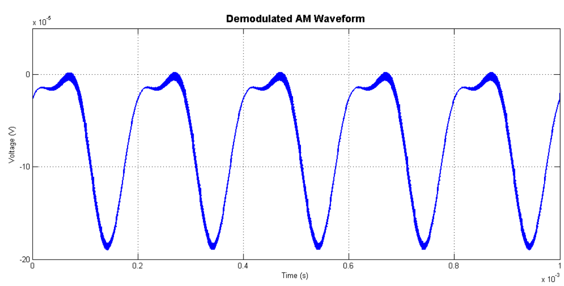

Fig. 9. Demodulated AM Waveform that results from the circuit of figure 7.

Modulation (AM). V1 generates the modulating signal and A1 modulates the signal onto the carrier. The components R1, R3, C1, D1 and D2 represent a model of the fence and the rusty joint. V2 represents the galvanic cell generated by the fence staples. The remainder of the circuit to the right is a simple two stage resonant filter to remove the carrier and leave the modulated signal. This particular design was chosen because it requires no external power supply to operate, a must for a radio system such as this. The demodulated signal is measured across R4. The resulting demodulated waveform is reproduced in figure 9. It is noticeably distorted but does clearly demonstrate demodulation of the original waveform from the carrier wave.

V. Conclusion

A thin layer of rust has been measured to have non-linear conductivity. The circumstances required to achieve such a characteristic are quite specific and mechanically fragile, and so are unlikely to occur often in practice. We attribute the nonlinearity to a tunnelling effect associated with a thin layer of material (iron oxide) separating the steel of the wires. A modest voltage, such as occurs in the case of an operating electric fence, can destroy the thin isolating layer. A well-designed fence remote control can be arranged to deliver a sufficient voltage to break through such non-linear joints.

Furthermore, the nonlinear effect can produce mixing and detection effects. We show how a fence might demodulate AM radio transmissions.

Acknowledgment

The authors would like to thank the Gallagher Group for supporting this research, and the Callaghan Institute for a "Technology New Zealand Capability Education Funding Fellowship". Without this funding and support, this research would not have been possible. The authors would also like to thank Tony Smith for his support.

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