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Noise properties in breaking and loose contacts and their effect on quality degradation of digital signal

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Abstract: Electric contact discharge is subject closely related to digital information transmission, and integrity of digital signals for realizing high reliablility transmission. This kind of problem is a part of EMC (electromagnetic compatibility). From such a viewpoint, contact noise problems will be mentioned which disturb and degrade digital signals. The induction noise and radiation noise from discharge, electrostatic discharge (ESD), and connector related fundamental subject will be mentioned.

Key words: EMC (electromagnetic compatibility), Electric contacts, Discharge, Induction noise, Radiation noise, ESD (electrostatic discharge), Connector

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INTRODUCTION

The author has for a long time studied both EMC (electromagnetic compatibility) and electrical contacts. ICREPEC, 2007 will be one of the best conferences to promote the study of electrical contacts related system reliability, because electrical contacts and connectors are inevitably used in most of all electric or electronic, information and communication systems, and their reliabilities are affected by the performance of electrical contacts. This paper will concentrate on the subject of electrical contacts discharge noise that disturbs and/or degrades information signals.

In this article, we will overview the problems concerning electric discharge in electrical contacts from the signal integrity point of view because electric discharge produces induced and/or radiated electromagnetic (EM) noise that disturbs electric signals and degrades the system reliability.

Electric discharge has many aspects which we simply classify as normal arc discharge, intermittent discharge, and electrostatic discharge (ESD). They become noise sources and disturb transmission signals.

After viewing over the noise produced from contact discharge, the noise characterization, the noise simulator (composite noise generator: CNG), and its application to test signal transmission system will be mentioned.

CONTACT DISCHARGE AS A NOISE SOURCE

Contact discharge produces EM noise that may severely damage the high speed transmission signal, with these phenomena being the problems in EMC (Takagi and Taniguchi, 2005). We summarize the present subjects by separating them into induced noise and radiation noise (radio noise).

Before we proceed, we should see the contact circuit. Fig.1 is the fundamental contact circuit system that we deal with in this article. The load is resistive or inductive, C is generally parasitic but sometimes we introduce it for testing.

The circuit is simple, but the parameters shown in Fig.1 (only physical ones are shown, the environmental parameters are omitted) are independent variables, so many conditions should be tested and each condition produces different data.

A simple circuit like that in Fig.1 involves many complicated phenomena. Many unknown things have remained, but the investigations and researches mainly concern contact performance improvement. However, we have to notice that contact related devices have many disadvantages from the EMC point of view. The most annoying things are noise problems which are produced from electrical contacts.

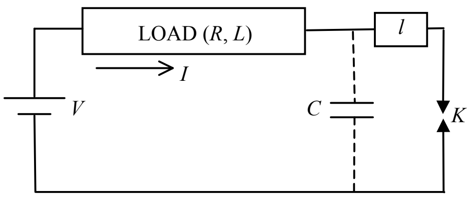

Fig.1 Contact circuit
LOAD: Resistance (*R*), inductance (*L*); *l*: Parasitic inductance; *C*: Capacitor (parasitic, and for testing); *V*: Battery voltage; *I*: Current; *K*: Contacts

Induced noise from switching contacts discharge

Not many induced noise phenomena have been scrutinizingly investigated so far, but the author's group has measured the noise induced from arc at breaking instant. As well known, arc waveforms are different from each other for load type and its value (resistive or inductive) depends on the contact materials as well (Holm, 2000). The author's group measured the induced noise from arc at the instant of break in resistive and inductive cases (Takagi and Inoue, 1981; Takagi, 1982).

When the load is inductive, the discharge waveform is quite different from that of resistive load (Takagi, 1982). The intermittent discharge is so-called showering arc which occurs between contacts when the inductive circuit is switched off. However, rather quiet intermittent discharge was found by Uchimura (1985) in the case of resistive load.

Radiation noise

1. Two types of discharge

According to Uchimura (1985), there are two types of discharge in the case of resistive load. One is intermittent discharge, another is normal arc. The intermittent noise occurs when the load is resistive with small current, but the normal arc occurs in the same circuit when the current is larger than some amount of value. There is a silent region (no discharging region) between intermittent discharge and normal arc.

It is interesting that no discharge region exists between intermittent discharge and arc discharge.

Intermittent discharge occurs in both cases of resistive and inductive load, and that in the case of inductive load has been called showering arc.

We summarize the contact discharge phenomena as follows: (1) Intermittent discharge (resistive load); (2) Showering arc (inductive load); (3) Normal arc discharge (resistive load).

The showering arc had been well investigated by Sawa (1982; 2004).

2. Radiation intermittent and showering arc discharge (resistive and inductive load)

The radio noise radiated from both intermittent and showering arc discharge was respectively measured by Uchimura (1985).

The intermittent discharge and showering arc are different from each other because the former occurs in the case of only very small gap length (very initial state of separation) and its power (energy) must be very small compared to that of the showering arc. Both characteristics are different from each other. The most prominent character is the effect of contact current on radiation level; the intermittent case is almost independent of current, on the contrary, the showering case is almost linearly proportional to current. Another thing we noticed was that almost the same level of radiation intensity were observed for both cases, although the intermittent discharge has much smaller energy than that of the case of showering arc discharge.

We see that the dependency of contact material is very small for radiation noise. This is almost the same as that of the intermittent discharge.

3. Radiation from normal arc

Normal arc occurring in arcing condition derived by Holm (2000). The arc characteristics are peculiar to the contact materials. According to Uchimura (1985), the radiation noise from normal arc is not so much dependent on contact current and material, but we should pursue more investigations. What we can say is that the frequency characteristic of the spectrum intensity is inversely proportional to frequency.

ESD (ELECTROSTATIC DISCHARGE)

ESD was a serious problem in the EMC since the early stage era in computer in the mid-1980's, when many unknown troubles occurred among the manufacturers. The empirically known culprit was the ESD. The pioneer who dealt empirically with this problem in the early stage in the world was Honda (1994), and in model analysis was Fujiwara (1994).

The group of Sato (Hiroshi Echigo, Shigeki Minegishi, Ken Kawamata) began their study on such a discharge phenomena as the events of distributed line with a small gap in a coaxial line that was controllable in gap length (Kawamata, 2004).

The gap length controllable system was installed at the end of semi-ridged cable, and the breakdown current was derived from the cable for measurement. The needle and flat metal surface target were provided.

6 MHz oscilloscope was used to carry out the experiments for every condition such as voltage, shape of needle tip, etc. One of the most interesting results was the characteristic of voltage vs rise time; that is, the rise time becomes slower as the breaking voltage increases. The same thing was mentioned by Fujiwara (2005). Another interesting one was the frequency spectrum characteristic, which sharply decreased with frequency, which may be due to cable characteristics (Honda, 1994).

DISCHARGE PHENOMENA IN SEPARABLE STATIC CONTACTS

The author's group found new phenomena: dark bridge observed along with micro-discharge in separable static contacts that separate very slowly (Ishida *et al*., 2005). The author thinks this phenomenon should be a fundamental one not to be ignored for information transmission system, because in future the signal transmission through power line (PLC: Power Line Communication) will commonly be used. In such a system, if the connector simultaneously used for both power supply and information transmission is suffered from loose contact, signal degradation will occur.

We should investigate this phenomenon from such a viewpoint and from the fundamental behavior of separable static contacts.

ELECTRICAL CONTACTS AND DIGITAL SYSTEM

Model of information signal and noise

Fig.2 shows a signal transmission model for analysis of the signal quality at the receiver *Rc*. The signal *S* is transmitted from transmitter *Tr*. The signal is smeared by the noise *N*. Due to the additive noise *N*, signal integrity cannot be maintained at the receiver.

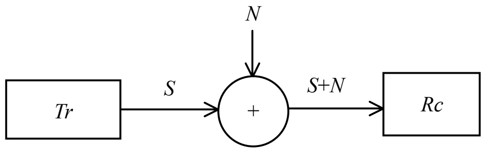

Fig.2 Signal transmission model

The contact circuit is simple (Fig.1) and the information signal transmission system looks also simple; however, the signal quality analysis is very complicated, because the noise character is so complicated. No quantitative analyses have been done for an analog signal because it cannot be characterized like a digital signal. But today, as all information signals are transmitted digitally, the signal characterization can be done quantitatively. The signal degradation can be expressed by a bit error rate (BER). If BER is zero, the signal integrity is maintained. The signal degradation can be qualified by the BER value.

When the noise is Gaussian, the possible transmission bits per second (channel capacity *C*) can be written by Eq.(1) with respect to bandwidth *W*:

$$C = W \log(1 + S / N), \tag{1}$$

where *S*/*N* is so-called signal to noise power ratio. Eq.(1) was derived by Shannon (1948).

However, actual man-made noise is always non-Gaussian. The electrical contact discharge noise just mentioned previously is also non-Gaussian. This means *SN* ratio cannot be simply calculated because measurement of discharge noise power is not so easy, but also in a digital system, a signal is vulnerable to impulsive noise which means BER due to impulse noise is different from that due to Gaussian noise.

Characterization of discharge noise

1. APD and CNG

Not only discharge noise but also all sort of general noise can be characterized by statistically. The noise amplitude probability is essential. APD (amplitude probability distribution) is used for characterization of the noise. When APD curve of the noise is linear on normal probability paper (NPP), the noise is Gaussian. Not so many contact discharge noises have been analyzed in such a way except the authors' data. The author and Inoue analyzed 1 MHz Ag contacts normal arc noise picked up by a coil and put it on the NPP (Inoue and Takagi, 1985). The results were not normal (non-Gaussian), but they have tried to approximate the data by the plural different Gaussian noises that had different variances, and from which they have succeeded to produce any noise by combining the plural Gaussian noises with different variances. This noise source is the CNG (Composite Noise Generator) or PCNG (Programmable CNG) (Inoue and Takagi, 1985; Takagi, 1995).

2. Mathematical model (Middleton)

A man-made noise is always non-Gaussian, for which mathematical treatment is difficult. But for some special non-Gaussian noise, the effective mathematical model was presented by Middleton (1979) from the case of additive impulse Gaussian noise that is very common in practice. The author and colleagues presented a noise generator which can generate Middleton type noise and applied it to test digital system (Suzuki *et al*., 1992).

CONCLUSION

We have seen the EMC aspect in electrical contact discharge. What we noticed is that electrical contacts have many complicated phenomena and that investigations on the EMC aspect are in an infant state now. But users of electromagnetic relays and connectors should notice that such devices have complicated EMC problems. At least, the followings may become comprehensive to the leaders:

(1) Although the contact circuit is very simple, the phenomena are so complicated that many have remained research subjects.

(2) Contact open-close operations are inevitably followed by discharge phenomena.

(3) There are three types of discharge: intermittent discharge at low current, normal arc due to resistive load, and showering arc due to inductive load.

(4) There is a case in which the noise level from contact discharge is independent of contact current.

(5) ESD phenomena are a part of electrical contact phenomena because they occur when charged electrodes approach to make contact.

(6) Static contacts (connector) have EMC problems of micro-discharge at loose contact.

References

Fujiwara, O., 1994. ESD Source Model and Occurrence Electromagnetic Field. Proc. of the RICE Symposium, Tohoku University, p.95-100 (in Japanese).

Holm, R., 2000. Electric Contacts, Theory and Applications (3rd Ed.). Reprint of Fourth Completely Rewritten Edition 1967, Springer.

Honda, M., 1994. Fundamental Aspects of ESD Phenomena and Its Measurements. Proc. of the RIEC Symposium, Tohoku University, p.79-86 (in Japanese).

Inoue, H., Takagi, T., 1985. Statistical measurement of 1 MHz noise induced from arc and composite noise generator (CNG). *The Transactions on Communications (Japanese Edition)*, **J68-B**(12):1506-1512.

Ishida, H., Taniguchi, M., Takagi, T., 2005. Precise Measurement of Dark Bridge Between Micro-Gap Electrical Contacts in a State of Thermal Equilibrium Condition. IEEE 2005 Instrumentation and Measurement Technology Conference, IM5382, Ontario, Canada. [doi:10.1109/IMTC.2005.1604358]

Kawamata, K., 2004. Wideband Measurement of Transient Variations Due to Micro-gap Discharge. 1st IEEE EMC-S Sendai Chapter Colloquium, Tohoku University, (in Japanese).

Middleton, D., 1979. Canonical Non-Gaussian Model: Their Implications for Measurement and for Prediction of Receiver Performance. 3rd Symposium and Technical Exhibition on Electromagnetic Compatibility, Rotterdam.

Sawa, K., 1982. Generation of Discharge and Intermittent Arc at Very Short Gap. Ph.D Thesis, Keio University (in Japanese).

Sawa, K., 2004. IEEE CPMT Ragnar Holm Scientific Achievement Award Lecture. The International Conference on Electrical Contacts, Seattle.

Shannon, C.E, 1948. A mathematical theory of communication. *The Bell System Technical Journal*, **27**:379-423, 623-656.

Suzuki, H., Shizuya, H., Takagi, T., 1992. Composite noise generator (CNG) with random pulse stream (RPS) generator for immunity teat in digital system. *IEICE Trans.*, **E75-B**(3):183-187.

Takagi, T., 1982. Theoretical and Experimental Study of Switching and Ignition Noise in Motor Vehicles. Proc. of the 5th International Symposium on Electromagnetic Compatibility, Zurich.

Takagi, T., 1995. Composite noise generator (CNG) as a noise simulator and its application to noise immunity test of digital systems and TV picture. *IEICE Trans. Commun.*, **E78-B**(2):127-133.

Takagi, T., Inoue, H., 1981. Induced Electromagnetic Noise from Contact Discharge-Measurement and Statistical Characteristics. IEEE International Symposium on Electromagnetic Compatibility, Boulder.

Takagi, T., Taniguchi, M., 2005. EMC Aspect on Electrical Contacts. Annual Convention of IEICE, CS-5-1, March, 2005/06/23.

Uchimura, K., 1985. Experimental Research on Electromagnetic Noise from Contact Discharge Ph.D Thesis, Tohoku University (in Japanese).