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HANDBOOK

Mitigation measures for telecommunication installations

Part 2: Case Studies

ITU-T
Telecommunication
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2008

THE TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU

HANDBOOK

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Introduction

This part 2 of the mitigation measures handbook provides mitigation case studies, divided into three areas: emission and induced noises, overvoltage and overcurrent, and power frequency problems.

Each case study is first given a title and described by identifying the type of trouble, source of trouble, system affected, location and keywords involved. This is followed by descriptions of the system configuration, measurement or searching techniques or experiment used and the mitigation method, results or conclusion. Finally, the relevant ITU-T K-series Recommendations are referenced.

The mitigation used for a particular case may not be the solution to a similar problem in real telecommunication environments. Readers should analyse their own problem using the measurement or searching technique or experiment described in the case study.

CONTENTS

Case study #	1.1
Title	Acoustic noise troubles caused by an amateur radio base station
Type of trouble	Acoustic noise.
Source of trouble	Amateur radio base station.
System affected	Customer's equipment.
Location	Customer premises.
Keywords	Immunity, amateur radio.
Version date	2004-01-01

System configurations

Acoustic noise trouble occurred at a customer premises. The customer complained that a strange sound could be heard through the handset of the telephone. The telecom line pair was changed as a usual mitigation measure; however, the problem continued.

The system configuration of this issue is shown in Figure 1.1-1. The telephone set was connected to the host equipment. The customer premises were located 20 to 30 m away from an amateur radio base station. The frequency of the radio base station was 7 MHz and its radiation power was estimated at more than 100 W. After the investigations, the electric field strength was found to be greater than 110 dBμV/m around and in the customer premises. The noise was caused by the electromagnetic waves of the amateur radio base station.

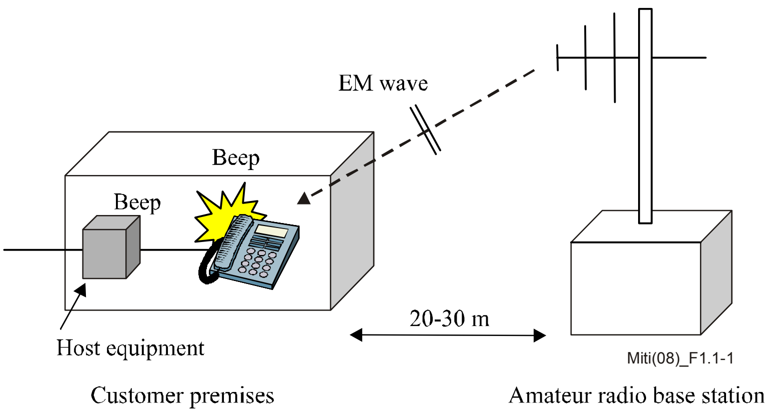

Figure 1.1-1 – System configuration

Measurement/Searching techniques/Experiment
To consider mitigation procedures, testing using a shielded room was carried out as shown in Figure 1.1-2. The test can be also carried out in an anechoic chamber. A signal generator was used to generate a 7 MHz signal with 80% amplitude modulation, which was then amplified and loaded to the monopole antenna. The resulting electromagnetic wave was applied to the telephone set and its host equipment. The monopole antenna was used as radiation antenna, and a loop antenna was utilized as receiving antenna. The loop antenna was connected to an electric field strength receiver (RX).

The immunity level of the telephone sets are shown in Figure 1.1-3. The immunity level of Telephone 1 was less than 110 dBμV/m, compared to the electric field at the real location. After testing, it was found that noise can be induced through the telecom port and the inner port connecting the telephone and the handset cord.

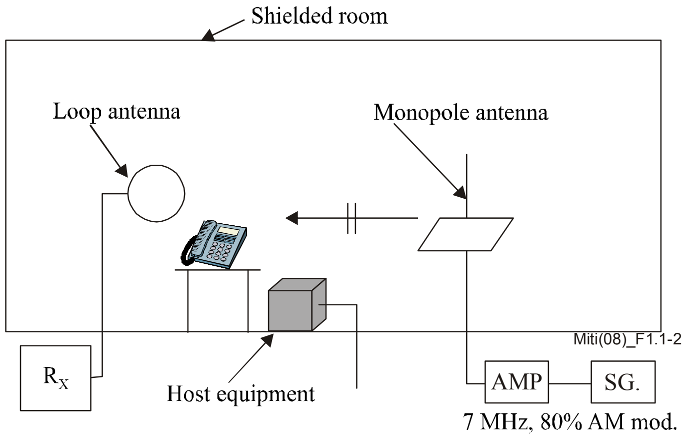

Figure 1.1-2 – Experiment configuration

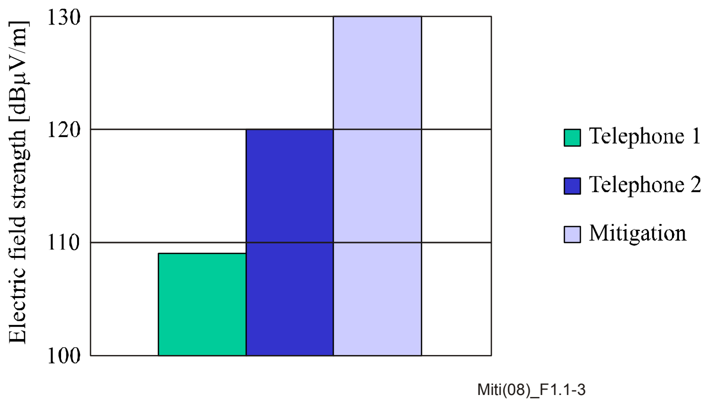

Figure 1.1-3 – Immunity levels of the telephone sets

Mitigation method/Results/Conclusion
In this case, common mode filters and capacitors were used as a mitigation measure. For the telephone set, a common mode filter was inserted into the inner port of the telephone: A 1000-pF capacitor was applied to the handset of the telephone set. The capacitance was selected considering the insertion loss and noise reduction. As for the host equipment, a common mode filter and capacitors were applied to the telecom port and the inner ports. The central frequency of the common mode filter was set to 20 MHz in this case. This filter is also effective for a 7 MHz electromagnetic field. One port of the capacitances was connected to the earth terminal of the host equipment. According to the mitigations, the immunity level is more than 130 dBμ/m; the acoustic noise problem was resolved.

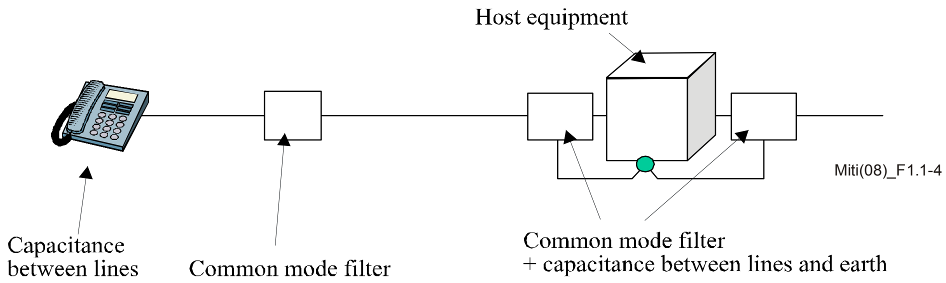

Figure 1.1-4 – Mitigations

References
Rec. ITU-T K.37; Annexes A and B.

Case study #	1.2
Title	Acoustic noise troubles caused by switching noise of digital subscriber unit (DSU)
Type of trouble	Acoustic noise.
Source of trouble	DSU.
System affected	Customer's equipment.
Location	Customer premises.
Keywords	DSU, mutual coupling.
Version date	2004-01-01

System configuration

Acoustic noise trouble occurred at a customer's premises. The system configuration is shown in Figure 1.2-1. A remote terminal (RT) was used, as well as single mode fibres for the trunk lines. Metal lines were distributed using a metallic internal cable. Telephones, facsimile machines, and DSU were connected to the cable. There was no radio base station around the location. The electric field strength was not so high. After an ISDN service was introduced, the acoustic noise problem occurred. The line connected to the telephone was changed; however, the noise problem still continued.

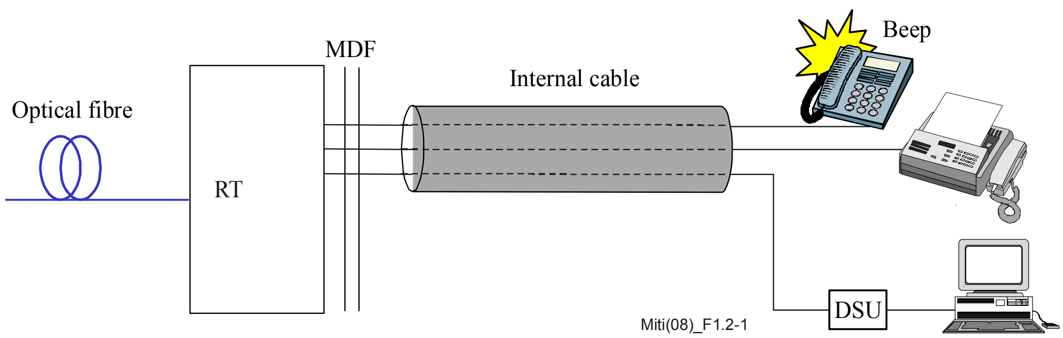

Figure 1.2-1 – System configuration

Measurement/Searching techniques/Experiment

To identify the noise sources, electric current wave shapes were measured using a current probe as shown in Figure 1.2-2. First of all, the current in the line connected to the telephone where the acoustic noise problems occurred was measured. The current level was not high but could cause malfunction of the telephone. However, the wave shape had little relation with the telephone because inverter noise spectrum was included in the wave shape. Next, the current on the line connected to the DSU was measured (see Figure 1.2-3). The current level was 240 $mA_{p\text{-}p}$, which is not a low level. As a result of the investigations, it was confirmed that the electric current noise originated at the DSU power source because the noise disappeared when the DSU was turned off. The noise current from the DSU travelled over the internal cable. In the cable, mutual coupling phenomena occurred. The noise current from the DSU induced noise current on the line connected to the telephone. The current caused malfunction of the telephone and the noise was detected in the telephone.

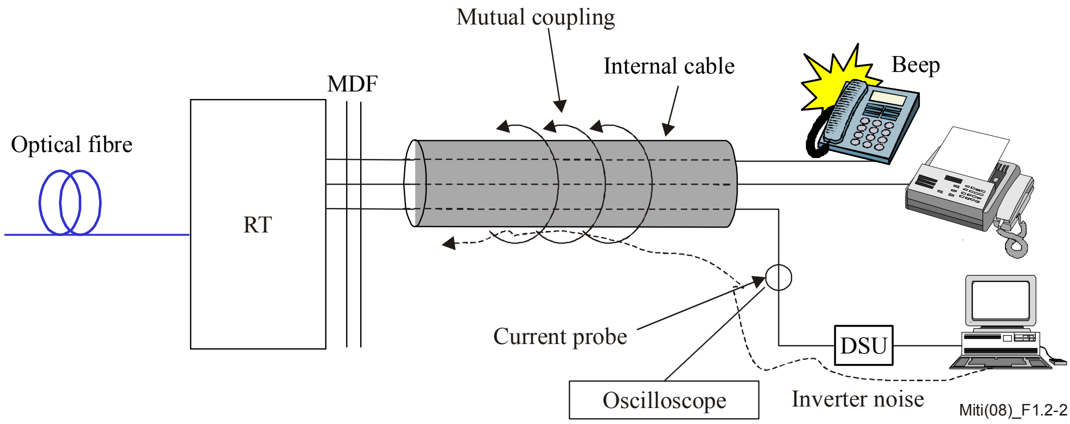

Figure 1.2-2 – Measurement of noise current on lines

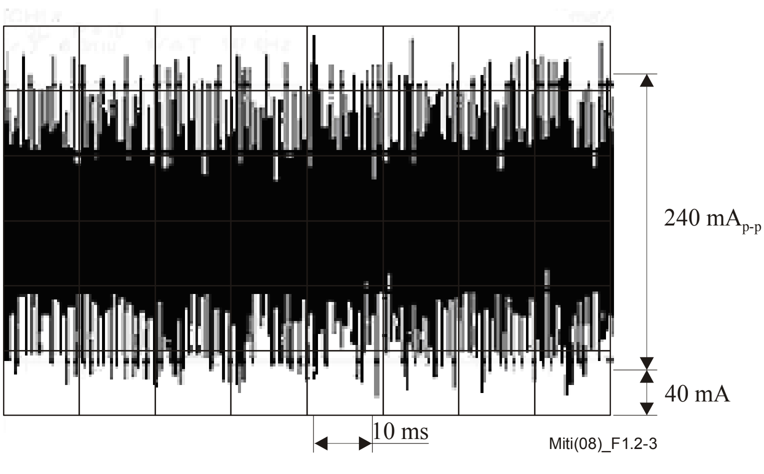

Figure 1.2-3 – Current wave shape in the line connected to the DSU

Mitigation method/Results/Conclusion
The centre frequency of the DSU switching noise was about 10 kHz; therefore, the common-mode filter (F2-40K) for mitigations shown in Figure 1.2-4 was selected. The central frequency of the filter was 40 kHz and it was effective for the switching noise of this case. By applying the filter, the current in the line connected to the DSU was reduced, as shown in Figure 1.2-5. The current level was reduced to less than 10 mA and the acoustic noise problem was solved.

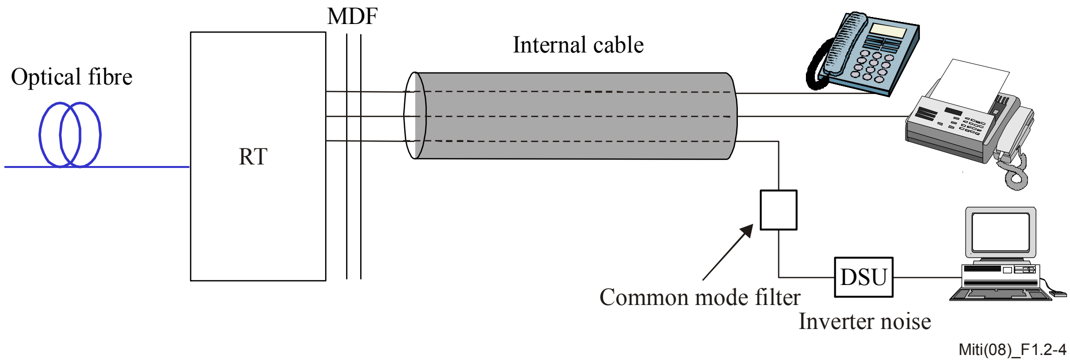

Figure 1.2-4 – Applied mitigation using common mode filter

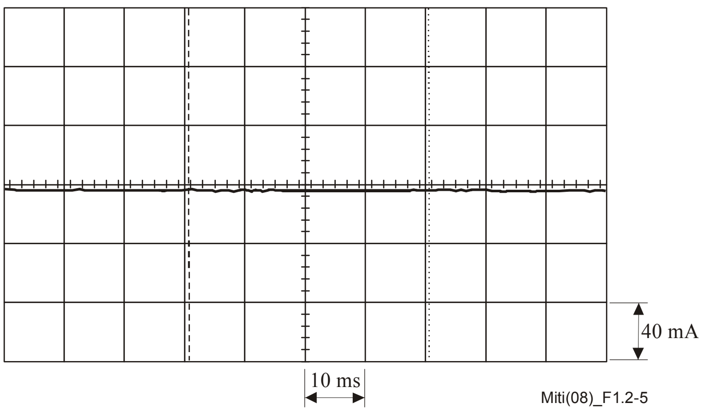

Figure 1.2-5 – Wave shape of the current in the line connected to the DSU, after the mitigation

References
Rec. ITU-T K.37; Annexes A and B.

Case study #	1.3
Title	Acoustic noise troubles caused by switching noise of an elevator (lift)
Type of trouble	Acoustic noise.
Source of trouble	Elevator.
System affected	Customer's equipment.
Location	Customer premises.
Keywords	Elevator, mutual coupling, switching noise.
Version date	2004-01-01

System configuration

Acoustic noise trouble occurred at a customer premises. The customer complained that the acoustic noise could sometimes be heard; however, it was not clear what the trouble source was. The system configuration of this issue is shown in Figure 1.3-1. At the customer premises, the telecom lines and power mains cable for the elevator (lift) were parallel in the cable duct. The motor of the elevator used a switching power source. The telecom line connected to the telephone set was also connected to the MDF where the power transformer was located. The telecommunication line was changed; however, the acoustic problem continued.

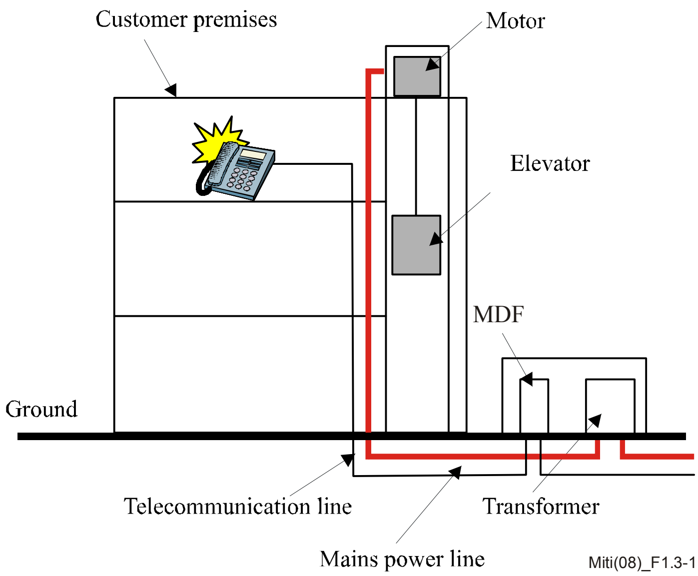

Figure 1.3-1 – System configuration

Measurement/Searching techniques/Experiment

To solve this acoustic problem, the current in the telecommunication line was measured (Figure 1.3-2). The common mode current wave shape is shown in Figure 1.3-3. A typical period 200-300 μs periodic characteristic can be seen in the figure. Its major frequency is about 5 kHz and it was estimated that the noise source must be a switching power source. The investigations showed that the power mains cable was wired parallel to the telecommunication line, and that the telecommunication line was connected to the main distribution frame (MDF) room, where the mains power transformer was located.

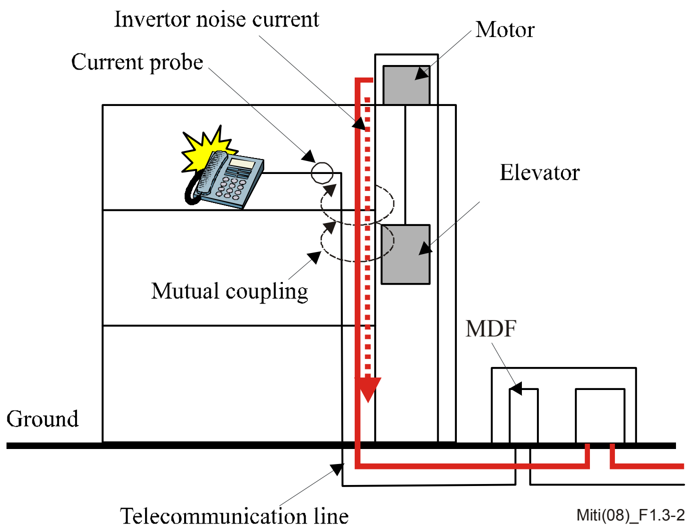

Figure 1.3-2 – Measurement of noise current

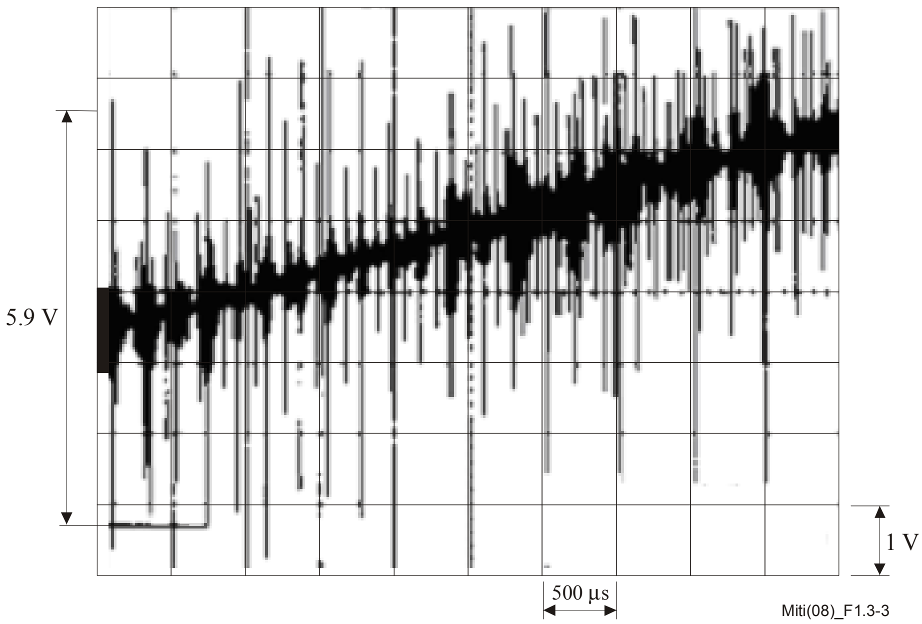

Figure 1.3-3 – Current wave shape on the line connected to the telephone

Mitigation method/Results/Conclusion

The acoustic problem originated in the mutual coupling of the switching noise of the motor. To solve this problem, it was decided to apply a common mode filter to the telecommunication line and an isolation transformer to the mains power line (see Figure 1.3-4). The isolation transformer with a filter was attached to the mains power line, and the filter was located as near as possible to the motor, so as to prevent the switching noise from travelling along the cable. The common mode filter at the MDF was attached to the telecommunication line.

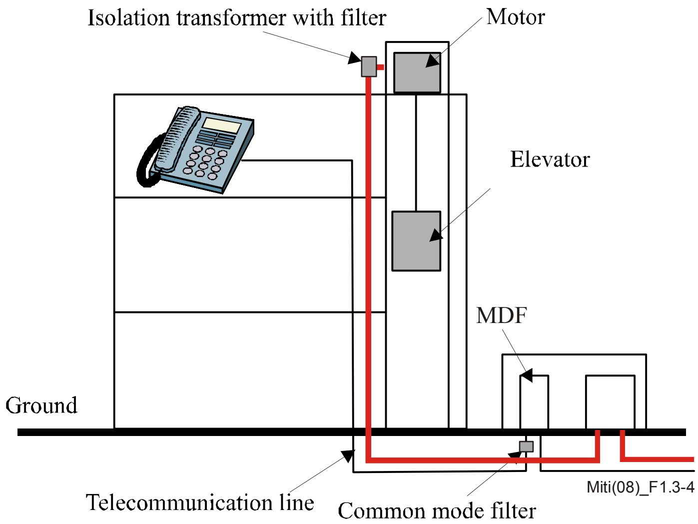

Figure 1.3-4 – Applied mitigation using common mode filter

References

Rec. ITU-T K.37; Annexes A and B.

Case study #	1.4
Title	Emission from telephone equipment affecting an amateur radio
Type of trouble	Acoustic noise.
Source of trouble	Host equipment of telephone system.
System affected	Customer's equipment and office equipment.
Location	Customer premises, Telecommunication centre.
Keywords	Emission, amateur radio, common mode choke, filtering.
Version date	2004-01-01

System configuration

Acoustic noise interference occurred in an amateur radio installed on the second floor of a building (see Figure 1.4-1). The building's first floor is an office and workshop and the second floor is a living space. The affected frequencies were 145.00 and 144.00 MHz. A lot of office equipment and manufacturing equipment was installed on the first floor. The distance between the amateur radio and the noise source (core equipment) was 10 m.

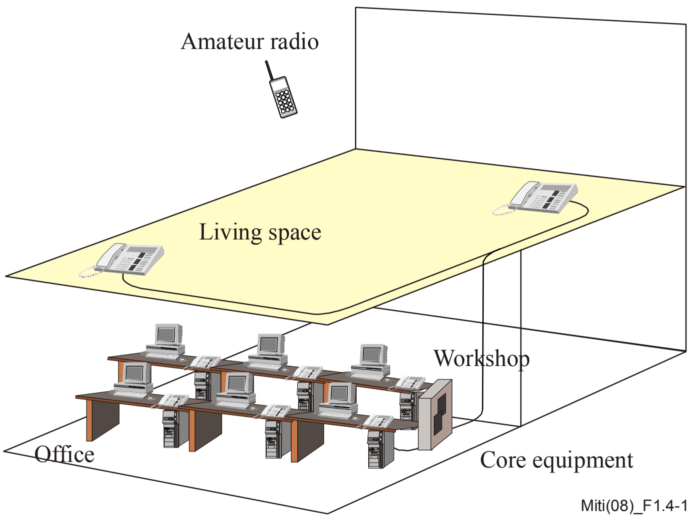

Figure 1.4-1 – System configuration

Measurement/Searching techniques/Experiment
1) Search technique (to find which equipment emitted the noise) The emission source was searched for using a hand-held amateur radio tuned to the affected frequency. The affected area could be searched roughly. The electrical equipment acting as the emission source was determined by turning off the power of the suspected equipment. It was found that the emission source was the core equipment of the telephone system. 2) Mitigation trial a) A ferrite core was installed in the power line and in the telephone line of the core equipment. b) The core equipment was wrapped in aluminium foil. c) An insulated conduction sheet was pasted onto the rear of the circuit board. As a result, the acoustic noise affecting the amateur radio decreased slightly, but still remained. 3) Search technique 2 (to find the noise source) When a noise is emitted, there must be both a noise source and a noise radiator. Both elements were searched for. a) The system was measured in an anechoic chamber and the noise level was checked. b) The noise source was searched for using a near-field magnetic probe and a spectrum analyser, as shown in Figure 1.4-2. In this case, a probe (Figure 1.4-3) was used. This probe had a coil consisting of several turns installed ahead of the coaxial cable. The coil was connected between the inner and outer conductors. Areas close to board components IC8 and Xtal4 had higher noise levels. c) The noise level was checked by trial and error in an anechoic chamber when a mitigation device such as a capacitor or ferrite core was installed.

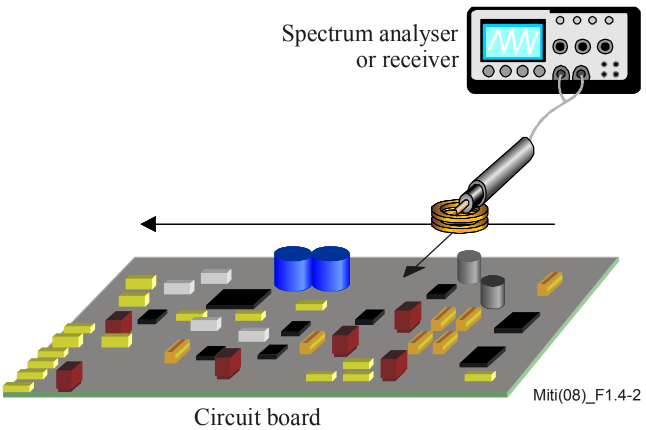

Figure 1.4-2 – Searching for the noise source

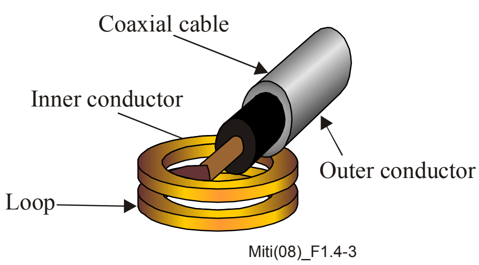

Figure 1.4-3 – Loop antenna

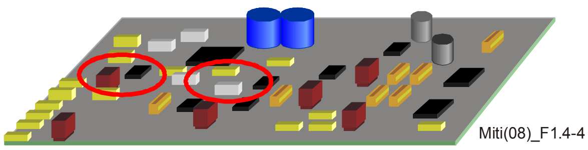

Figure 1.4-4 – Result of noise search

Mitigation method
The following definitive mitigation methods were applied:

1) An insulated conduction sheet was pasted onto the circuit board and a capacitor was put between the GND of the circuit and the sheet (Figure 1.4-5).
2) A ferrite bead was installed at the base of Xtal4 (Figure 1.4-6).
3) A capacitor was installed between VCC and GND of IC8 (Figure 1.4-7).
4) Ferrite cores were installed on all lines (Figure 1.4-8).

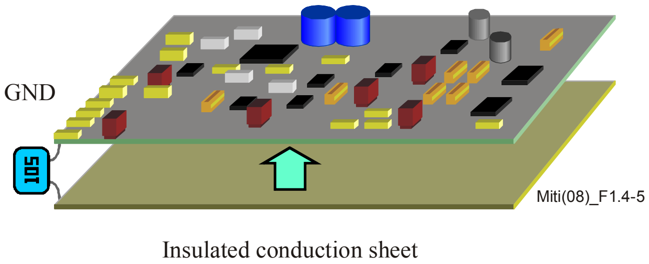

Figure 1.4-5 – Conduction sheet

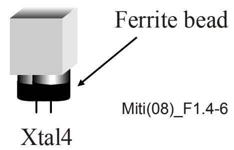

Figure 1.4-6 – Ferrite bead

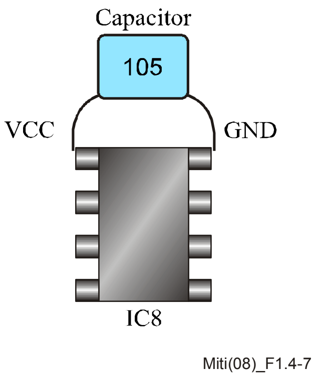

Figure 1.4-7 – Capacitor

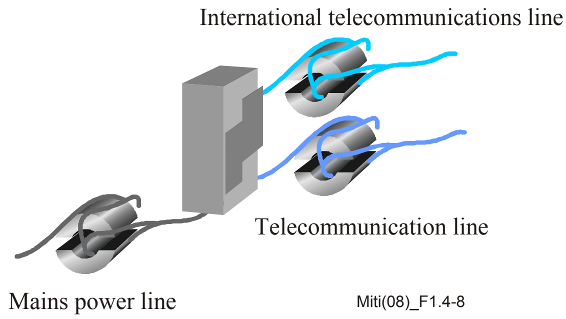

Figure 1.4-8 – Ferrite core

NOTE 1 – System integrity must be confirmed.

NOTE 2 – Changes to the system must be reported to the customer and are outside the guarantee in the future.

Case study #	1.5
Title	Acoustic noise troubles caused by an electric fence
Type of trouble	Acoustic noise, degradation.
Source of trouble	Electric fence.
System affected	Customer equipment, line.
Location	Customer premises, outdoors.
Keywords	Power transmission line, transformers, screening, mutual coupling earth connection, optical components, optical insulation.
Version date	2004-01-01

System configuration
A customer complained about intense noise troubles on his analogue telephone line. The acoustic noise was permanent with varying intensity. Because of the kind of the problem (clicking interference at regular intervals), it was suspected that the cable (10-pair 0.4-mm copper cable) was being affected by an electric fence close to the cable route, which did not make part of this installation. An optical fibre cable, with its screen earthed at both ends, was running parallel to the 10-pair copper cable. The optical fibre cable, the multiplexer (optical-electrical) and the 10-pair copper cable ended at the same distribution point. However, a long electric fence was located in the neighbourhood of the optical fibre cable, although not at the copper cable site. The system configuration of the location is shown in Figure 1.5-1.

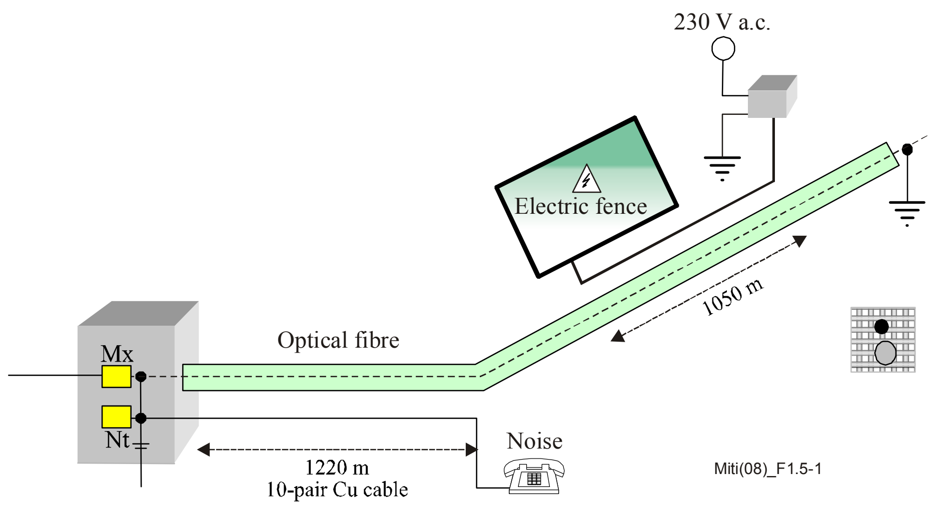

Figure 1.5-1 – System configuration

Measurement/Searching techniques/Experiment

The electric parameters of the line were in line with the requirements. A 148-Vp-p longitudinal voltage line-to-ground at customer installation was measured (Figure 1.5-2). The major frequency of the transients was about 8 kHz and decreased after 2.5 ms (Figure 1.5-3). The transients repeated at 1.3-second intervals. Measurements were also made at the distribution point. On the screen of optical fibre transient, currents with about 27 Ap-p were measured. The peak-to-peak voltage recorded between the earthing conductor of the screen and the ground at the distribution point was 340 Vp-p (Figure 1.5-4). The asymmetrical supplying cable of the electrical fence, which was situated along the route of optical fibre, was identified as the source inducing the transients.

Through the screen that was earthed at both sides (screen resistance 13.5 Ω), the optical fibre was the source for the induction into the parallel copper cable. The metallic foil of the 10-pair cable was earthed on only one side, connected to the earth of the distribution point.

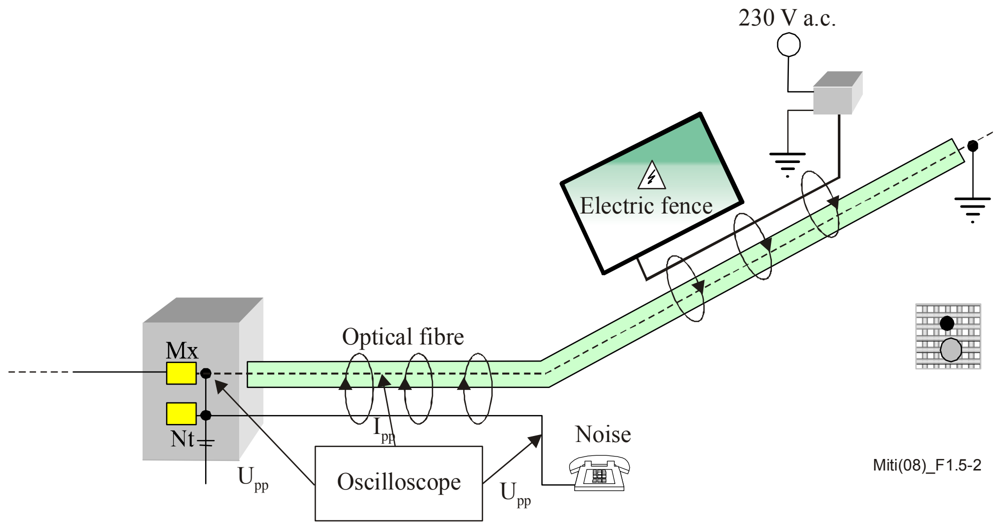

Figure 1.5-2 – Measurement system

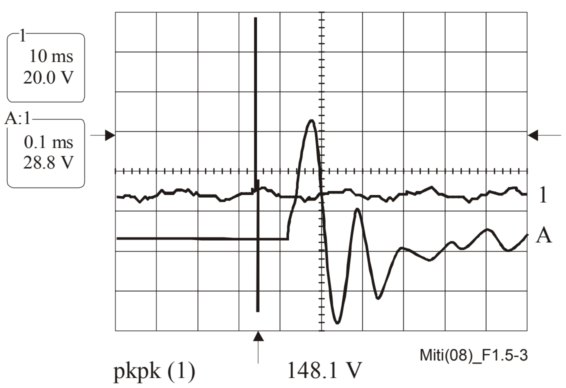

Figure 1.5-3 – Voltage transient on the copper – cable

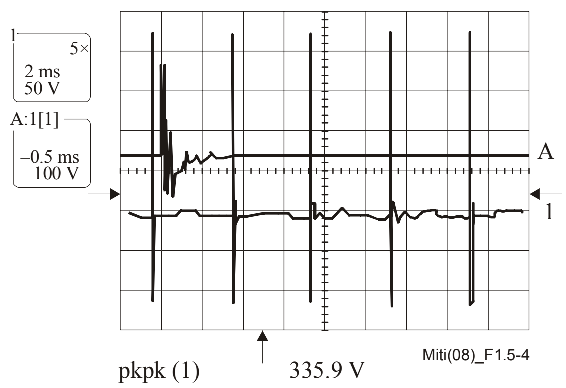

Figure 1.5-4 – Voltage transient on the screen of the optical fibre

Mitigation method
First, the metallic foil of the 10-pair copper cable was connected to the main earthing terminal at the customer site. As a result, the transient voltages were reduced to 1/6 of the value that had before mitigation (Figure 1.5-6). The remaining voltage, which was about 23 Vp-p, still caused some clicking noise. To solve this problem, it was decided to install a neutralizing transformer at the distribution point. This led to a decrease of about 3 Vp-p, making the disturbance vanish. The buried power supply cable of the fence was poorly isolated, i.e., the connecting points were not isolated. Because of the disturbances, the following solution was found, in agreement with the owner of the electric fence: increase the distance between the power supply cable of the electric fence and the optical fibre cable, and properly isolate the connectors.

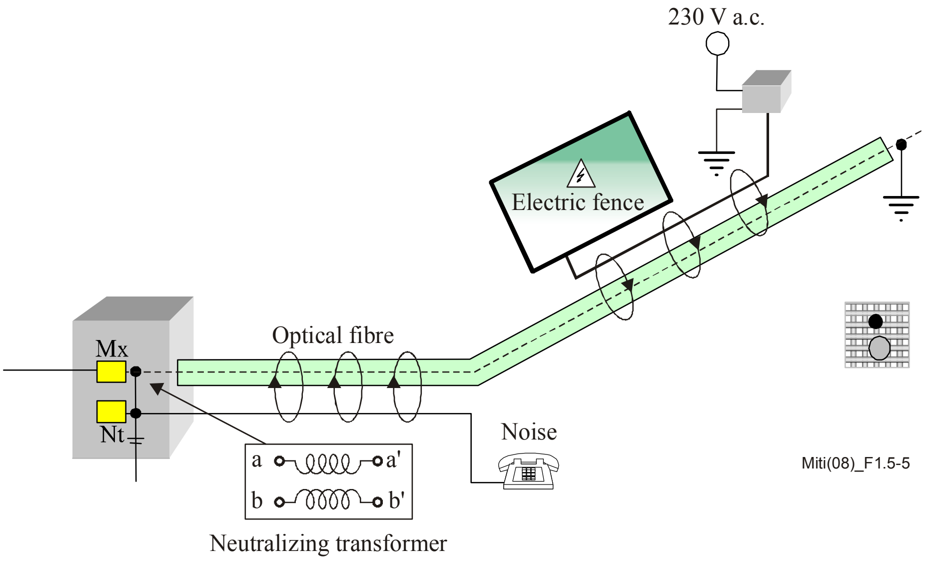

Figure 1.5-5 – Mitigation method

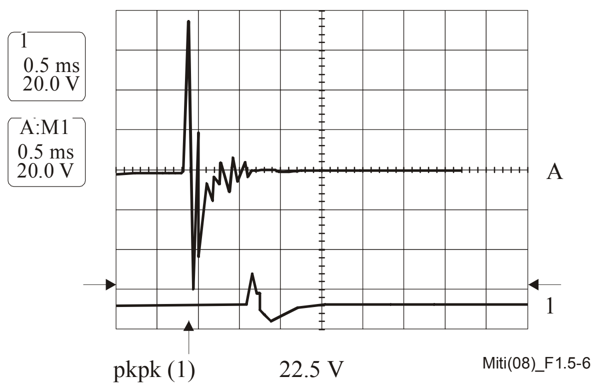

Figure 1.5-6 – Mitigation results

Case study #	1.6
Title	Electric fence interference
Type of trouble	Acoustic noise, degradation, abnormal operation, loss function.
Source of trouble	Electric fences used to protect property or keep animals contained generally use a high voltage (8 kV) impulse (ms) to energize the fence at intervals of about 1 second. Noise/EMC.
System affected	Customer's equipment, office equipment, access network.
Location	Customer premises, telecommunication centre.
Keywords	Immunity, common mode chokes, screening, filtering.
Version date	2004-01-01

System configuration
A normal PSTN or ISDN telephone line can be affected. Close proximity to the source generally results in noise being generated (on buried and aerial telephone cables running parallel to the electric fence) up to a few tens of metres away.

Searching techniques
Detection is simple, as regular clicks, every second, can be heard on the telephone, or data errors are received at regular intervals.

Mitigation method /Results/Conclusion
A number of mitigation methods are available in such circumstances. Ideally, the problem should be solved at the noise source. The installation of the electric fence should be checked to ensure that it meets the manufacturer's guidelines: the generator earth should be remote from any other power earths and of low enough resistance so as not to cause excessive step potential (< 200 V, 1 m from the earth point). The fence should be installed on suitable insulation; vegetation should not touch (should be cut back) the fence wires; in areas of high earth resistivity, a base wire connected to the generator earth point should be installed; alternating the fence wires forming the fence (e.g., from the bottom to the top – earth/HV/earth/HV) can help reduce stray currents and provide a more effective fence; sitting the generator mid-way along the parallel section of the route and energizing the fence in both directions can help minimize inductive effects; avoiding making a total loop around a field with the wire (break inserted at a post) can reduce loop antenna effects. If the above does not succeed or the fence owner is uncooperative, then mitigation measures need to be taken on the telephone system. First, ensure that the cable balance of the network is at least 60 dB; otherwise, mitigation measures will not be as effective. Most electric fence interference affects the customer end-terminal equipment. The fitting of a choke and drain circuit will in most instances cure the problem (Note that a connection to earth is necessary for the drain to be effective.). See Rec. ITU-T K.37. In the small number of instances where the telecommunication centre equipment is being overloaded by the induced impulses, then the fitting of 100 mH common mode chokes can be quite effective. If the telecom cable has a screen available along the section parallel to the fence, then ensure it is earthed at each end, and at a few intermediate points of the parallelism. The filters described above are generally very effective, especially with services such as pair-gain or ISDN (see Rec. ITU-T K.37).

References
Rec. ITU-T K.37; Annexes A and B.

Case study #	1.7
Title	Infrared movement-sensing lights
Type of trouble	Degradation, abnormal operation, loss function.
Source of trouble	Outdoors PIR lighting was creating noise on a number of telephone lines, sufficient to cause DSL circuits to fail.
System affected	Customer's equipment/Access network.
Location	Customer premises.
Keywords	Emission, other (solved at source).
Version date	2004-01-01

System configuration
A normal PSTN line, enabled for ADSL, suddenly started to suffer from large numbers of transmission errors, particularly in the early evening, when it got dark, and last thing at night. A number of customers appeared to suffer from the problem.

Measurement/Searching techniques/Experiment
A RF detector indicated that there was harmonic power noise present, but no industry likely to cause the problem. Using the RF detector to search the lead-in cables to each of the premises found one to be particularly high in the harmonic noise levels. Further investigation revealed that the owner of the premises had used a 'spare pair' in his telecoms cable as a power feed for his PIR (passive infra red) outside lamp. The problem was compounded in that the lamp controller also performed a dimming action. Once the lamp was correctly wired, away from the telecoms cable, the problem was solved. A similar lamp was procured for EMC testing, as it was thought to possibly be too high on emissions.

Mitigation method/Results/Conclusion
Solved at source, rewired the lamp correctly.

References
Rec. ITU-T K.37; Annexes A and B.

Case study #	1.8
Title	Medium-wave AM radio interference, PMR (private mobile radio) radio interference
Type of trouble	Acoustic interference due to demodulation of the RF at semiconductor junctions within the telephone.
Source of trouble	Either a local AM radio transmitter in the MW band, or a private mobile radio transmitter, e.g. from a taxi service.
System affected	Customer's equipment.
Location	Radio station, outdoors.
Keywords	Immunity, emission LF broadcasting, HF broadcasting, amateur radio, citizen band transceiver, common mode chokes, filtering.
Version date	2004-01-01

System configuration

A normal PSTN telephone line, generally with (even a small amount, 50-100 m) aerial cable entering the customer premises. (All underground routes tend not to suffer from this type of interference.) Proximity to radio transmitting sites, such as the offices of taxi companies, citizen's band radio or MW AM stations make telecommunications installations particularly vulnerable. The higher the power, the greater the influencing distance. Not all customers on a road are necessarily affected as the coupling depends both on the orientation of the cable with respect to the transmitter and on the equipment the customer is using. Some terminal equipment is more susceptible than others to RF imbalance effects.

Search techniques

The detection of such problems is fairly simple: the telephone engineer simply listens to the line and recognizes the noise originates in a radio transmission.

Mitigation method/Results/Conclusion

Generally, if the transmitter is being used in agreement with its transmission licence, there is nothing that can be done to solve the problem at source.

The fitting of small common mode chokes to the incoming access network cable will normally solve the problem. It is important to mitigate the interference as soon as possible, i.e., just before the network termination, such that all cables within the premises are protected from the interference by one filter. There are currently many thousands of these filters fitted to customers' lines working successfully.

Any filter used should be suitable for the transmission of DSL services. If they are not correctly designed, they will introduce too much loss for such services.

References

Rec. ITU-T K.37; Annexes A and B.

Case study #	1.9
Title	Electric railway interference
Type of trouble	Acoustic noise, degradation, abnormal operation, loss function.
Source of trouble	Electric railways within a few kilometres of telecom systems.
System affected	Customer's equipment.
Location	Customer premises, outdoors.
Keywords	Electric railway, common mode chokes, screening, filtering.
Version date	2004-01-01

System configuration

Normal PSTN line. Customers hear noise come and go, coincident with trains coming/going into sections of track. It can be determined from the noise level (and tone) if the train is accelerating or decelerating. If booster transformers are used on the electrification system, then the sudden cut-in/out of the noise is very evident as trains enter and leave the section.

Measurement/Searching techniques/Experiment

Customers suffer; noise creates audible and data problems, even to the extent that dialling out does not proceed. Railway noise tends to be different from normal power harmonic noise in that it tends to be at a low level when no trains are in the section and then varies dramatically when a train arrives. Having knowledge of the timetable or a view of the line helps in determining if it is due to the trains. The noise is typically due to the multi-pulse rectifiers used in the power conversion of the motor and the spread of the return currents. Very little of the noise can be attributed to airborne effects.

Even when good mitigation measures have been employed, noise can sometimes re-occur. In most instances, this has been found to be due to poor track cleaning practices, which have resulted in numerous damages to earth bonds between rail and the return wire, thereby increasing stray currents in the earth.

Mitigation method/Results/Conclusion
A number of mitigation methods are available, though ideally it is better to solve the problem at source. It is imperative that the telecom operator is consulted when the electrification system is being planned and auto or booster transformers are suitably positioned to minimize induction effects due to the return currents. The balance of the pairs affected should be checked (> 60 dB), such that induction effects are minimized in the network cable. Measures that can be taken by the telecom operator to reduce the noise problem are to use screened cables, well earthed at the end of the parallelism as well as at numerous points along its length. If a screened cable is not available, then spare pairs, an old cable or a copper strip, earthed in a similar way can be almost as effective. Other measures may be to use induction-neutralising transformers (INTs) if a large number of customers are affected, or for fewer customers the use of common-mode chokes and drain circuits or even pair-gain systems. Occasionally, none of the above appears to work; this has been traced to the noise being conducted to the power system and local earth, such that all the customer internal wiring has an induced voltage on it. Fortunately, these are not too common. There is currently no easy solution to this case.

References
Rec. ITU-T K.37; Annexes A and B.

Case study #	1.10
Title	RF welder interference
Type of trouble	Acoustic noise/Degradation.
Source of trouble	RF welders and coupling of the RF into the telephone with resultant demodulation at semiconductor junctions into "white" noise.
System affected	Customer's equipment, office equipment.
Location	Customer premises.
Keywords	High-frequency welder, common mode chokes, filtering.
Version date	2004-01-01

System configuration
Normal PSTN circuit adjacent to a factory that uses an RF welder. Noise, sounding like loud "white noise", is only present during welding operations. Customer has normal telephones and wiring.

Measurement/Searching techniques/Experiment
Detection of the noise is by inference to the location. It is unlikely to be due to a far-away electric source. Coupling of the noise into the affected telephones/wiring tends to be over a short distance, so it does not normally affect many customers.

Mitigation method/Results/Conclusion
There is not always an easy solution to the problem. Internal wiring may need to be well screened to minimize RF pickup and/or the use of ferrite rings on telephone cords.

References
Rec. ITU-T K.37; Annexes A and B.

Case study #	1.11
Title	Noise caused by street lights
Type of trouble	Acoustic noise.
Source of trouble	Noise/EMC.
System affected	Customer's equipment.
Location	Customer premises.
Keywords	Emission/Other (arcing of relay contacts), other (solve at source).
Version date	2004-01-01

System configuration
A normal urban PSTN line, with 50-Hz-based noise present during the daytime on a number of customer lines served by the same distribution point. Initial thoughts were that the noise may be due to power equipment at a nearby industrial complex, but investigations on a weekend, when the factories were closed, still revealed the noise to be present.

Measurement/Searching techniques/Experiment
The engineer involved with solving the problem noticed that a street lamp was flickering during daylight hours, when it should have been off. The power company checked it and found the light sensor to be at fault, but after repairs the noise persisted. Further investigations revealed that the noise went off when the street lights all came on. This prompted deeper investigation with the power company. It resulted in turning off various lighting circuits in the area, and in each case the noise disappeared. Lighting load levels in the area were next investigated and found to be excessive for one particular set of circuits (the ones which had been turned off). The fault was found to be in a time-switch relay contact, which due to the overloading of the circuit was arcing continuously when the circuit was turned off, and had insufficient power to activate the lights. When the circuit was active, the relay contacts were closed, hence there was no noise. The arc noise was then coupling into the telecommunication cable.

Mitigation method/Results/Conclusion
Solve problem at source and work with power companies in tracing the problem.

References
Rec. ITU-T K.37; Annexes A and B.

Case study #	1.12
Title	TV interference problem due to telecommunication equipment
Type of trouble	Disturbance.
Source of trouble	Radiated emission.
System affected	TV receiver.
Location	Outdoors (near telecommunication centre or remote site).
Keywords	Radiated emission, TV receiver.
Version date	2008-02-29

System configuration

A TV interference problem occurred in the proximity of a building in which telecommunication equipment was installed.

A map of the location of this problem is shown in Figure 1.12-1, where the TV broadcast wave was propagating from the bottom-left to the upper-right domain. The TV receiver that experienced interference was installed just behind the building where the telecommunication equipment was set.

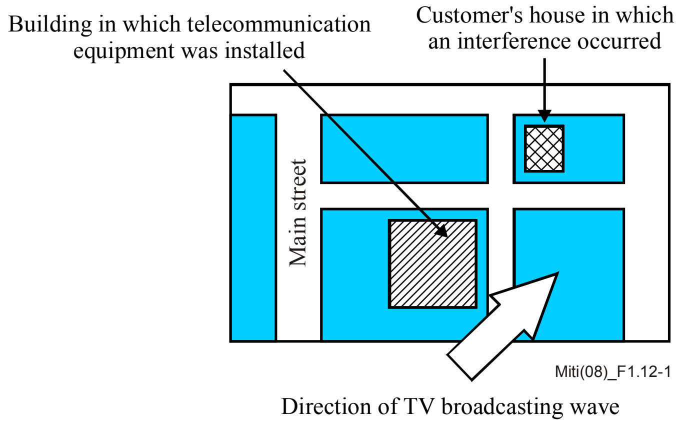

Figure 1.12-1 – Map of the EMI problem

Measurement/Searching techniques/Experiment

The customer claimed that stripes appeared on the TV screen in one TV channel. The broadcasting company investigated the cause of this EMI problem and found that the disturbance was due to EM waves radiating from the telecommunication building.

1 *Measurement of EMI source*

To find the source of this EMI problem, the following measurements were carried out:

a) TV broadcast signal level of the TV receiver, and

b) electric field distribution near the customer's house.

2 *Results of the measurements*

2.1 *Received TV signal level at the customer's house*

The received level of the TV broadcasting waves was measured with a spectrum analyser connected to a TV antenna at the customer's house. Figure 1.12-2 shows the measured frequency spectrum at the customer's house. An interference signal existed between the video and audio signal bands, and its level was about 22 dBµV. One can see that the D/U (desired/undesired) signal ratio was about 30 dB. From the experience of similar EM problems, the required level for the D/U ratio should be greater than 40 dB. Therefore, it was considered that this interference signal influenced the TV receiver, resulting in the generation of stripes on the screen.

2.2 *Measuring electric field distribution near customer premises*

Figure 1.12-3 shows the results of measuring the electric field distribution around this location. The results indicate that the highest electric field strength was observed near the building and that the measured level tended to decrease as the distance from the building increased.

2.3 *Measuring emissions near the telecommunication equipment in the building*

As a result, it was confirmed that the disturbance came from the building in front of the customer's house. The source of this interference was investigated and it was found that the interference signal radiated from transmission equipment in the building.

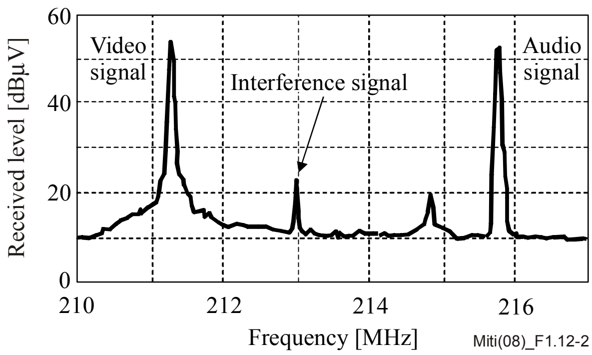

Figure 1.12-2 – Measured result of received signal level

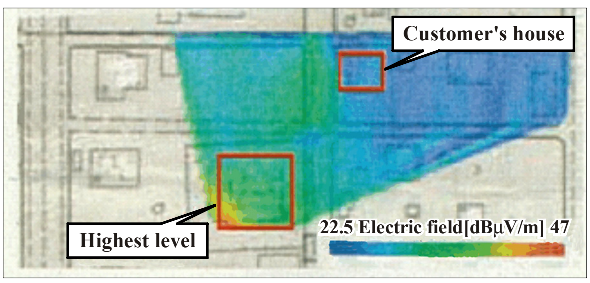

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Figure 1.12-3 – E-field distribution near the customer

Mitigation method/Results/Conclusion

The following countermeasures were performed to reduce the interference signal from the telecommunication equipment:

a) covering the building wall with shielded sheets (see Figure 1.12-4), and

b) clamping ferrite cores on cables connected to the transmission equipment.

After taking these countermeasures, the level of the interference signal decreased from 22 dB to 11 dB. As a result, the D/U ratio became more than 40 dB and the TV interference disappeared (see Figure 1.12-5).

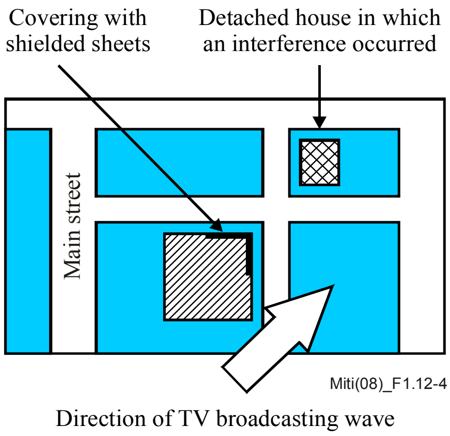


Figure 1.12-4 – Configuration of countermeasure

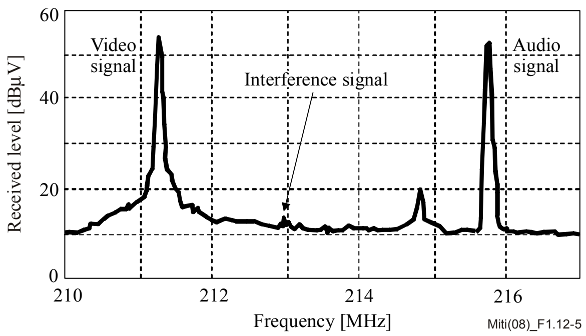


Figure 1.12-5 – Measured spectrum after countermeasures

Case study #	1.13
Title	EMC problem on next generation network (NGN) trial
Type of trouble	Disturbance.
Source of trouble	Conducted emission.
System affected	TV receiver.
Location	Customer premises.
Keywords	Radiated emission, TV receiver, IP set-top box (STB).
Version date	2008-02-29

System configuration

Figure 1.13-1 shows a system configuration in a next generation network (NGN) field trial. In this trial service, the home networks of trial users are connected to the NGN by an optical network unit (ONU) and a home gateway (HGW). High-quality video delivery services can be provided when both an IP-STB (IP set-top box) and a TV receiver are connected to the HGW. Analogue TV broadcasting is also provided by the traditional broadcasting equipment.

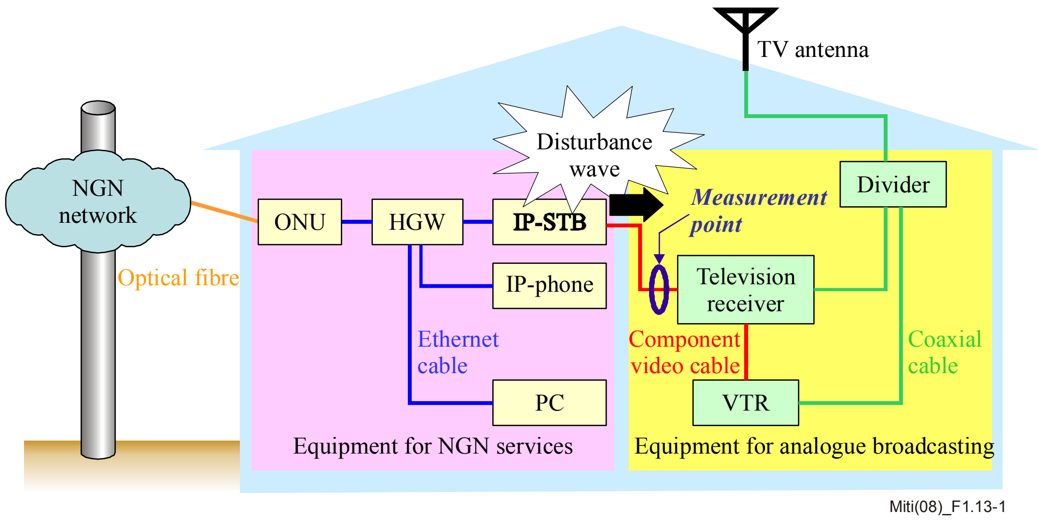
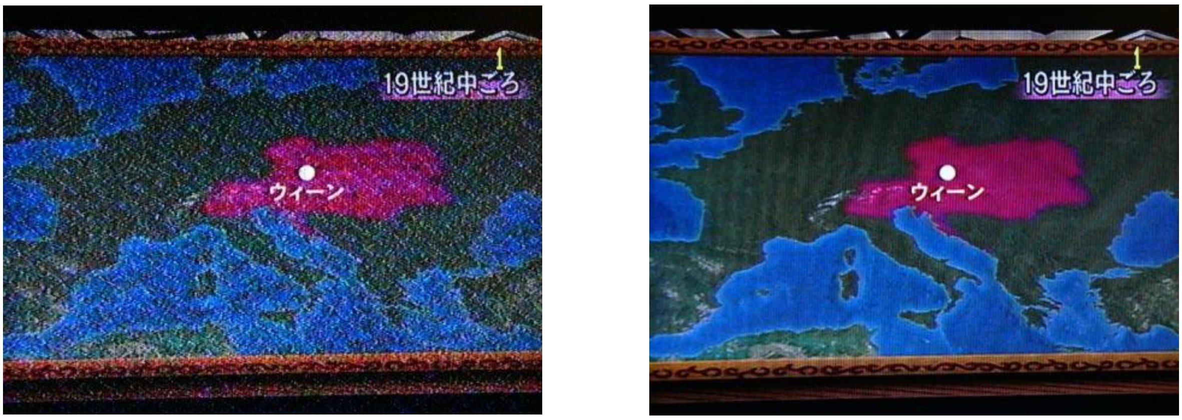


Figure 1.13-1 – A system configuration in NGN field trial

Measurement/Searching techniques/Experiment

As shown in Figure 1.13-2, video noise occurred in a channel (91.25 MHz) of analogue TV broadcasting when the IP-STB was turned on. This problem was solved when the IP-STB was turned off or when the component video cable was disconnected. The trouble source was considered to be the conducted disturbance wave from the IP-STB.



a) When the IP-STB was turned on   Miti(08)_F1.13-2   b) When the IP-STB was turned off

Figure 1.13-2 – Examples of TV screen: Video noise occurred when the IP-STB was turned on or off

Measured result of the conducted disturbance wave

The TV broadcasting signal and conducted disturbance wave were measured at the measurement point shown in Figure 1.13-1. Figure 1.13-3 shows the measured spectrum of the received signals. The desired signal to undesired signal (D/U) ratio was 25 dB when the IP-STB was turned on, and 45 dB when the IP-STB was turned off. As the D/U ratio of 40 dB is required for analogue TV broadcasting, this video noise on the TV picture was caused because the required D/U ratio was not being achieved.

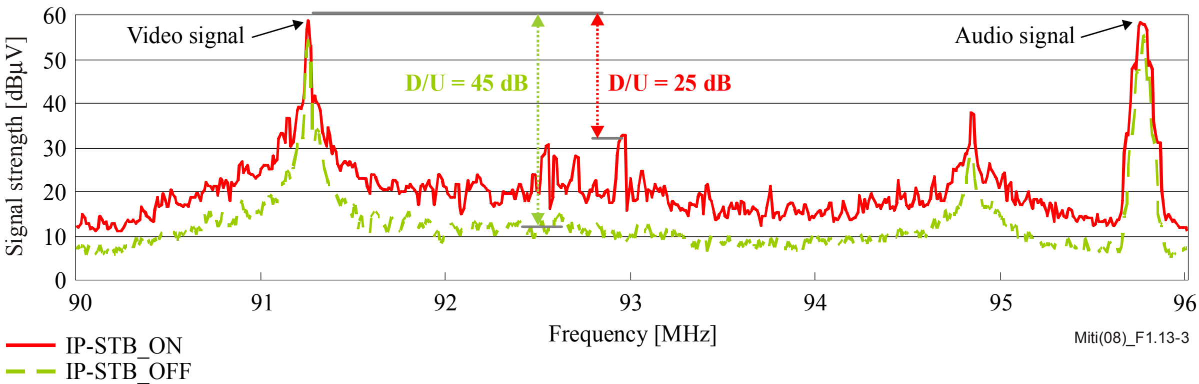


Figure 1.13-3 – Measured results of received signal spectrum

Mitigation method/Results/Conclusion

Mitigation method

As this problem was caused by the conducted disturbance wave from the IP-STB, four ferrite cores (Attenuation > 20 dB @ 10-100 MHz) were installed on the component video cable as shown in Figure 1.13-4. Figure 1.13-5 shows the variation of the D/U ratio after the installation of those ferrite cores. As the figure shows, the D/U ratio rose to about 45 dB, and this problem was solved.

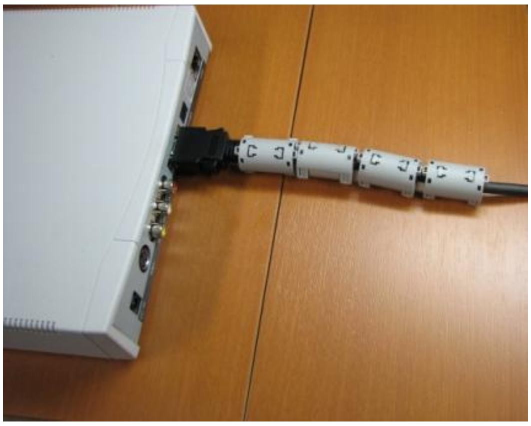


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Figure 1.13-4 – Mitigation by ferrite cores

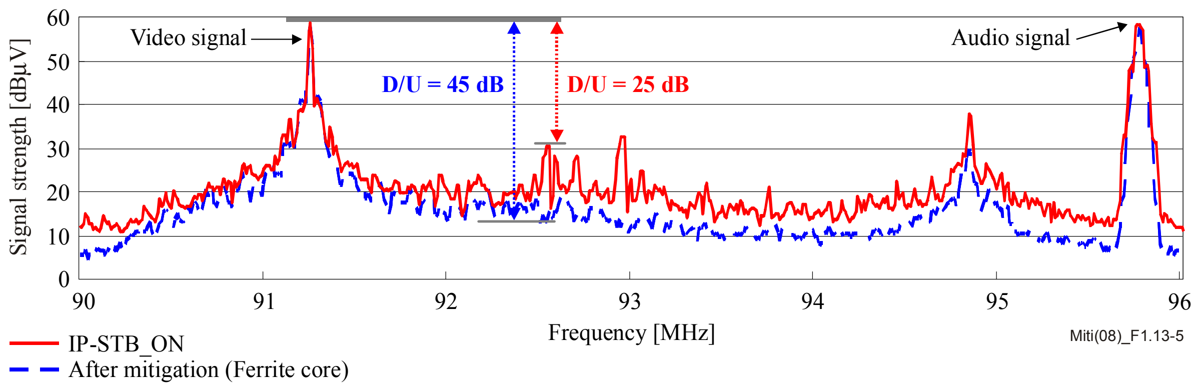


Figure 1.13-5 – Variation of D/U ratio after mitigation

Conclusion

In this NGN trial, communication and broadcasting equipments are connected by cables such as a video cable; therefore, both equipments can become disturbance sources. By checking the spectrum of measured signals, in this case, it was found that the IP-STB was a disturbance source. The requirements of video ports should be defined to prevent EMC problems on NGN services.

Case study #	2.1
Title	Lightning surge troubles on transmission equipment, TCM, and MUX
Type of trouble	Damage.
Source of trouble	Lightning surge.
System affected	Transmission equipment and MUX.
Location	Telecommunication centre.
Keywords	Damage, lightning surge.
Version date	2004-01-01

System configuration

The system configuration for a lightning surge trouble case is shown in Figure 2.1-1. As depicted in the figure, a transmission equipment, a TCM (transmission communication module), was located in the telecommunication centre, and there was a building with an antenna tower next to the telecommunication centre. Coaxial cables were used between the two buildings to connect the transmission equipment with the radio equipment. The earthing of the telecommunication centre and the earthing of the building were not connected to each other. The main distribution frame (MDF) earthing was not connected to the telecommunication centre earthing, either.

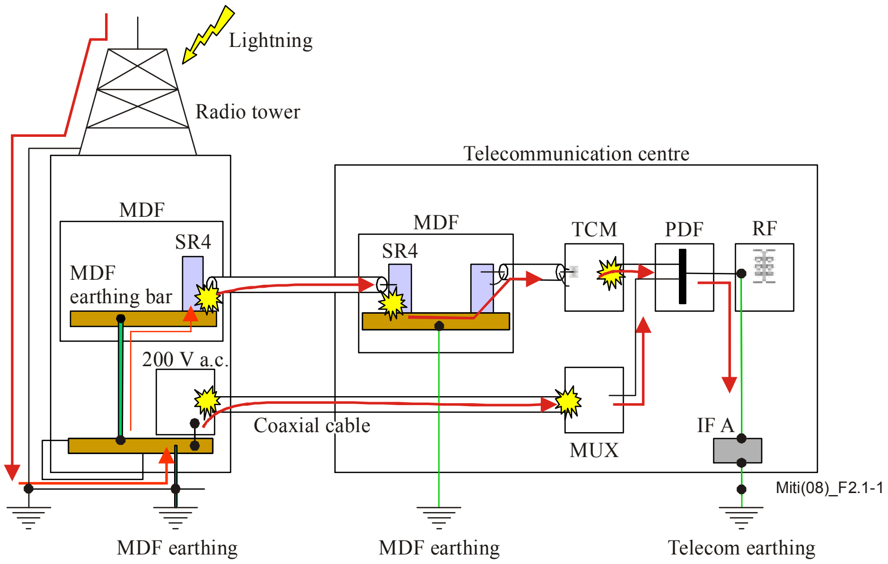


Figure 2.1-1 – System configuration

Measurement/Searching techniques/Experiment

As a result of the investigation, lightning surge strikes were detected at the radio antenna tower by visual inspection. Lightning surge current flowed through the tower, the earthing, power supply, MUX and TCM. It was considered that the surge current in the coaxial cables could damage the telecom equipment, TCM and MUX.

Mitigation method/Results/Conclusion

After investigations, it was confirmed that the transmission equipment, and the MUX could be damaged by surge current flowing from the building with the antenna tower, due to the electric potential difference between the building and telecommunication centre. For this telecommunication installation, a bonding network reduced the potential difference between the telecom centre and the other building. MDF earthing was also connected to the earth, as shown in Figure 2.1-2.

More detailed consideration should be given to connecting earthing networks when dealing with power systems of IT installations. The earthing resistance of IT systems is too high to absorb power fault current. If the earthing networks of several buildings are connected to each other, the total earthing resistance is lower than the original individual one. Therefore, national regulations or the relative Recommendations should be referred to.

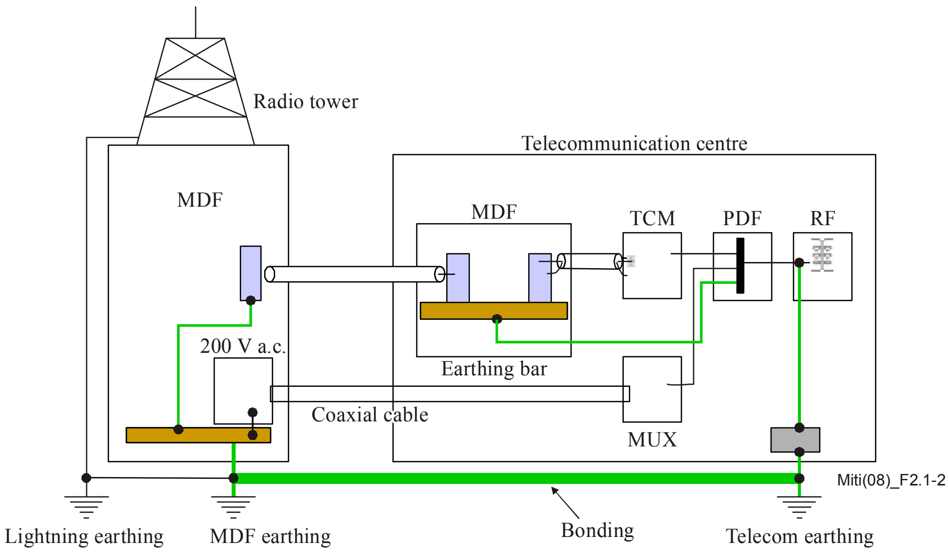


Figure 2.1-2 – Mitigation configuration

References

Recs ITU-T K.27, ITU-T K.35, ITU-T K.40, ITU-T K.56; Annex C.

Case study #	2.2
Title	Lightning surge troubles on CSM
Type of trouble	Damage.
Source of trouble	Lightning surge.
System affected	Transmission equipment.
Location	Telecom centre.
Keywords	Damage, lightning surge.
Version date	2004-01-01

System configuration

The system configuration and estimated lightning surge current flows are shown in Figure 2.2-1. The figure shows two telecom buildings in the same area. One telecom building has a high-altitude antenna tower with coaxial cables connecting it to building B. The two buildings' earthing systems were separated from each other, and the power mains were fed by different routes. However, a clock line was located between the two buildings, as shown in Figure 2.2-1. The antenna tower was not used at this installation.

The investigation determined that a lightning surge entered via the power mains of building A and that a power fault had occurred near the buildings. The surge current entered building A, flowing to its earthing. The increase in potential was caused by the lightning surge current. Buildings A and B were connected by the 64-kHz clock line; however, the earthing systems of the two buildings were independent from each other. Therefore, there was potential difference between a clock unit of the telecom equipment (CLK Unit), in Building A, and a clock interface of the CSM (Clock Supply Module) in Building B. As a result of surge current flows, the two equipments were damaged. It was estimated that the surge current went through the CSM to earthing E0.

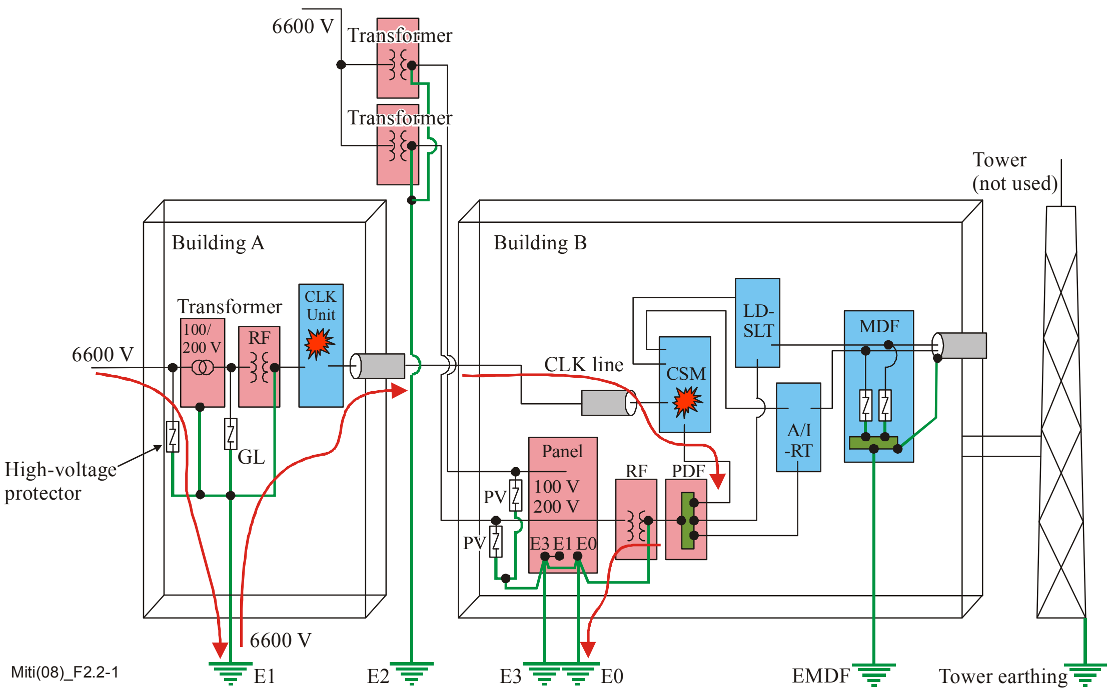


Figure 2.2-1 – System configuration and estimated surge current flows

Mitigation method/Results/Conclusion
The investigation revealed that this damage was due to the potential difference between the two buildings. Therefore, bonding of earthing systems should be used to reduce the potential difference, although the residual voltage difference might still remain. Therefore, it was recommended to insert an isolation transformer in the clock line, as shown in Figure 2.2-2. Additional mitigation measures were taken: the antenna tower that is not in use was removed; and to achieve an equipotential earthing system, earthings E0, E1, E3, and EMDF are connected to each other. More detailed consideration should be given to connecting earthing networks when dealing with power systems of IT or other systems. The earthing resistance of IT systems is too high to absorb power fault current. If the earthing networks of several buildings are connected to each other, the total earthing resistance is lower than the original individual one. Therefore, national regulations or the relative Recommendations should be referred to.

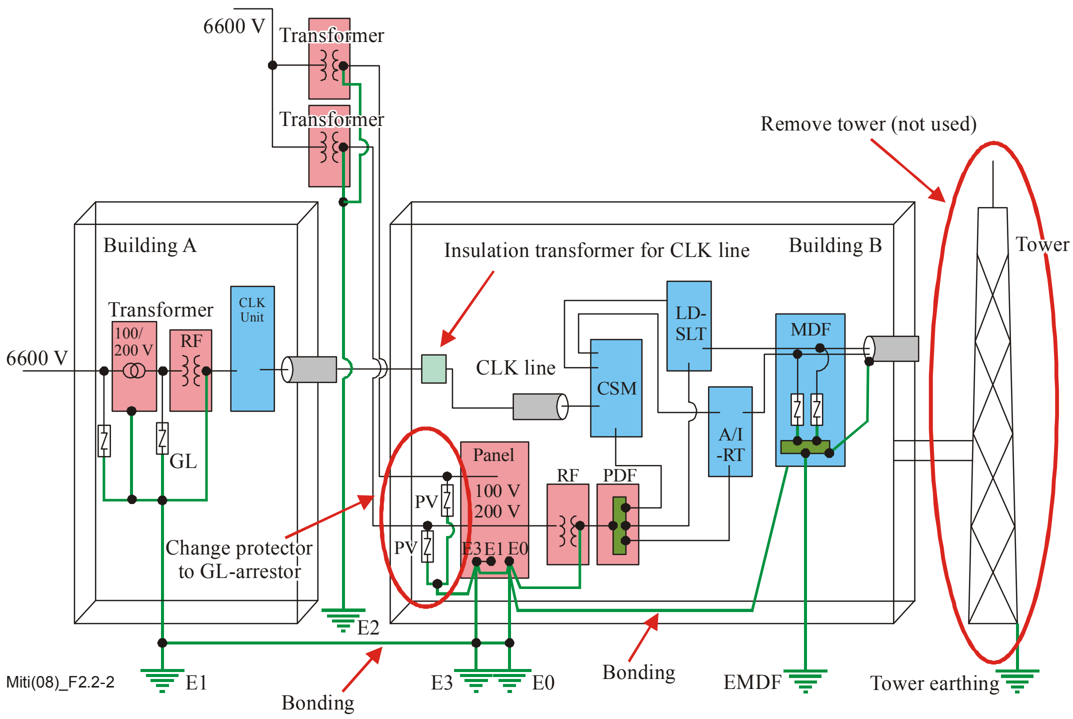


Figure 2.2-2 – Mitigation configuration

References
Recs ITU-T K.27, ITU-T K.35, ITU-T K.40, ITU-T K.56; Annex C.

Case study #	2.3
Title	Damage of LD-SLT and DCS telecommunication equipment
Type of trouble	Damage.
Source of trouble	Lightning.
System affected	Transmission equipment.
Location	Telecom centre.
Keywords	Damage, lightning surge.
Version date	2004-01-01

System configuration

A system configuration and an estimated current flow are shown in Figure 2.3-1. This telecommunication centre is a co-location building. Company A's telecommunication equipment and another company's equipment are sharing one same floor of the building. The radio equipment is connected to the antennas as shown in Figure 2.3-1. The power supply equipment located on the first floor is used to distribute DC power to both companies' telecommunication equipment. IBS in the figure is a DC power distribution module.

Company A's telecommunication equipment is powered through the IBS, while the other company's equipment is powered through the PDF, where PDF and IBS are power distribution frames. The PDF and IBS are also connected to the RF located on the first floor. DCS is a clock-supplying equipment that provides the clock signal to the radio equipment CR-822. CR-822 has a telecom interface and is connected to the switching equipment LD-SLT through a DF (a distribution frame). At this telecom centre, LD-SLT, SLM, DCS, and PSF were damaged by lightning.

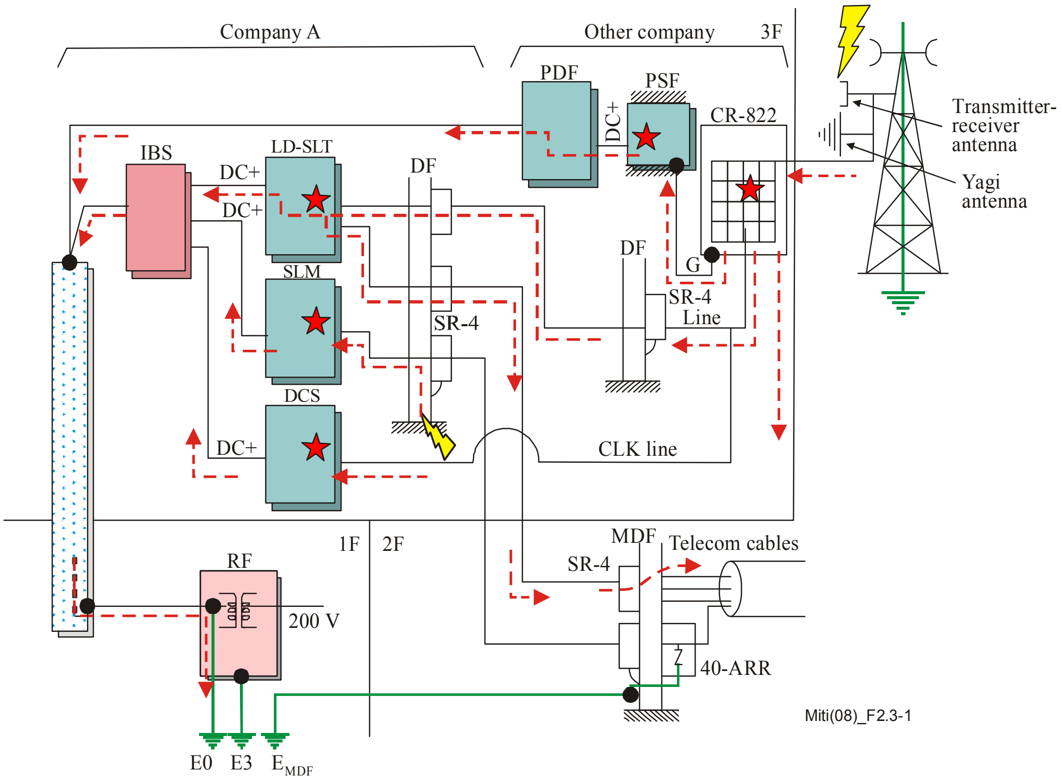


Figure 2.3-1 – A system configuration and an estimated surge current

Mitigation method/Results/Conclusion
It was estimated that direct lightning hit the antenna tower, and the surge current entered the telecom centre through the coaxial cables and the building structures, flowing into the radio equipment. The current entered the LD-SLT through the radio equipment, the SLM through the building structure or floor, and the DCS through the radio equipment. To prevent these damages from occurring again, it was required to do the following, as shown in Figure 2.3-2: – Bonding earthing networks. – Insert insulation transformer in CLK line. – Insert insulation bushing to isolate the equipment from building structures. – Change the cable panel with high insulation resistibility. More detailed consideration should be given to connecting earthing networks when dealing with power systems of IT or other systems. The earthing resistance of IT systems is too high to absorb power fault current. If the earthing networks of several buildings are connected to each other, the total earthing resistance is lower than the original individual one. Therefore, national regulations or the relative Recommendations should be referred to.

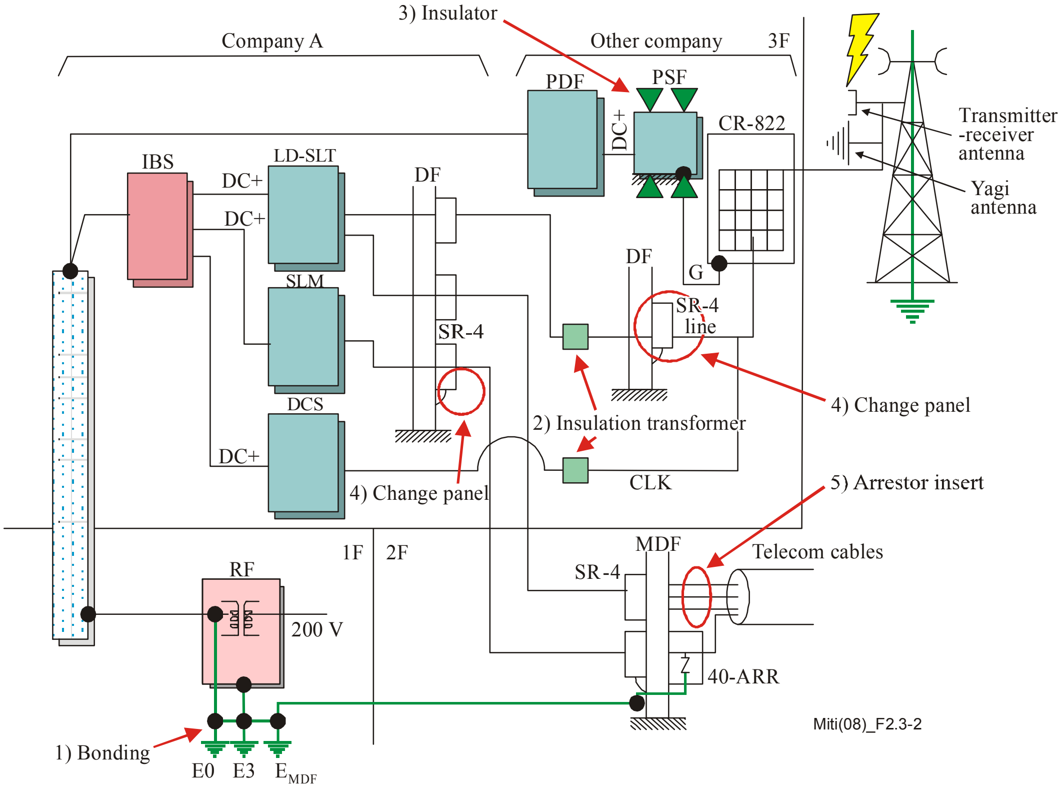


Figure 2.3-2 – Mitigation configuration

References
Recs ITU-T K.27, ITU-T K.35, ITU-T K.40, ITU-T K.56; Annex C.

Case study #	2.4
Title	Damage on ISM (I-Interface Subscriber Module)
Type of trouble	Damage.
Source of trouble	Lightning.
System affected	Transmission equipment.
Location	Telecommunication centre.
Keywords	Damage, lightning surge.
Version date	2004-01-01

System configuration

A system configuration and an estimated current flow are shown in Figure 2.4-1. At a lightning stroke, a switching equipment ISM (I-interface subscriber module) on the second floor, was damaged and its operation was halted. An ISM equipment located on the first floor was not damaged. No other equipment, aside from the ISM was damaged, and there were no error messages except those of the ISM equipment. The ISM on the second floor was connected to two power equipments, D-SSF and F-SSF.

The main power equipment is MR-48 on the ground floor, and the potential reference is a dc+ point in the MR-48. The current flowing through the ISM on the second floor followed a large loop, as shown in Figure 2.4-1. It is assumed that the equipment is easily affected by lightning.

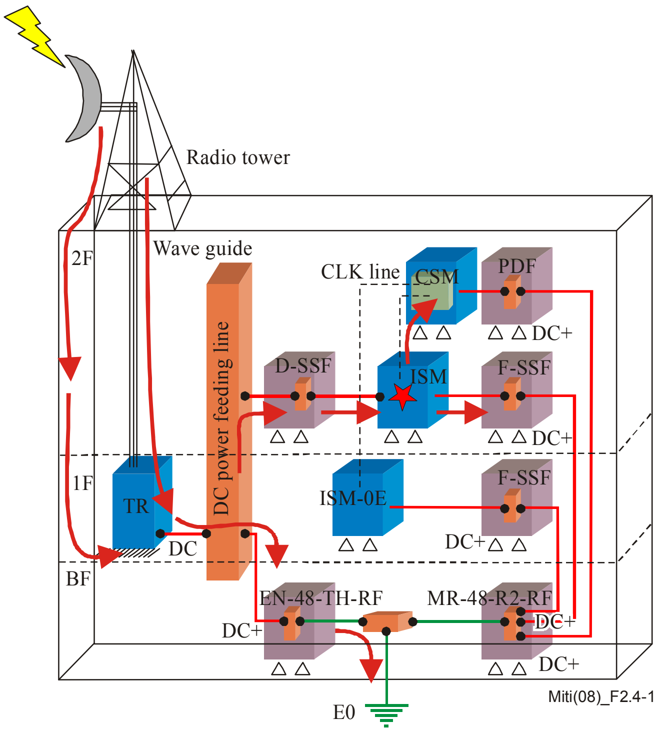


Figure 2.4-1 – System configuration

Mitigation method/Results/Conclusion
At this installation, the lightning struck the antenna tower; the surge current flowed into E0 earthing through the wave guide and building structures, and the DC power feeding line. The potential of E0 and also of the DC power feeding lines rose. The surge current penetrated ISM and flowed into E0, and then the ISM packages were damaged. To solve this problem, it was required to change the feeding routes as shown in Figure 2.4-2.

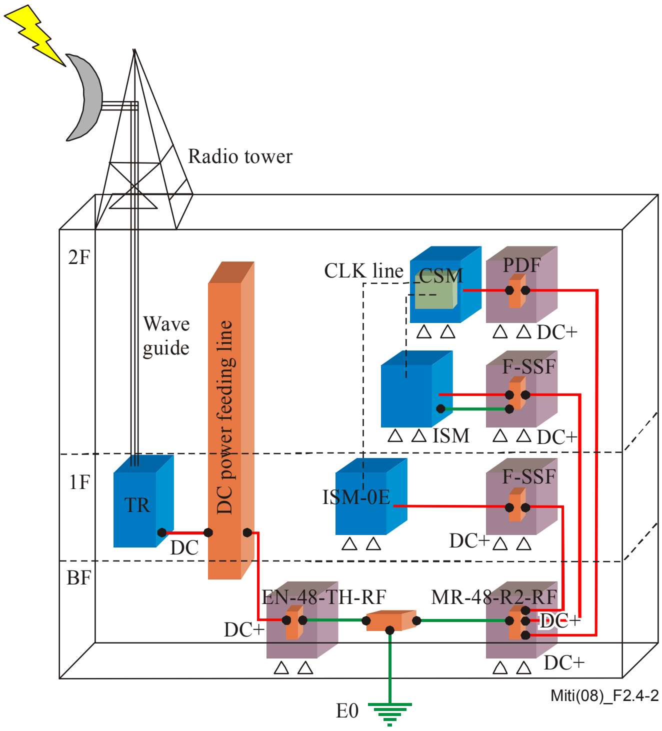


Figure 2.4-2 – Mitigation configuration

References
Recs ITU-T K.27, ITU-T K.35, ITU-T K.40, ITU-T K.56; Annex C.

Case study #	2.5
Title	Damage of 2-Mbit/s HDSL system
Type of trouble	Damage.
Source of trouble	Mistakes in bonding.
System affected	2-Mbit/s HDSL system using copper pair cable.
Location	Telecom centre.
Keywords	Damage, short circuit, mistakes in bonding.
Version date	2004-01-01

System configuration

In 1998, a new 2-Mbit/s HDSL (high bit rate digital subscriber line) system using paired copper cables was put into use by an operator after a pilot-use period. In the summer of 1999, several damages to it occurred. Analysis revealed that all the damaged systems had remote power feeding, and that the damage was caused by a short circuit in a protection component. The immediate action was to change existing equipment in exposed areas to local power feeding when possible, and start discussion with the manufacturer on future action.

Tests revealed that the origin of the damages was 50-Hz induction or earth potential rise voltages rather than lightning transients. The manufacturer decided to re-design the protection inside of the equipment to fulfil enhanced level power induction and earth potential rise requirements of Rec. ITU-T K.20. Systems having this new design were installed for pilot use in spring 2000 and they worked properly all of summer 2000. However, too many systems of the original type were again damaged in 2000. Maybe there were cases where the instruction to change to local power supply was followed. A field survey also revealed another reason: improper earthing of the equipment. A practical example is shown in Figure 2.5-1.

Miti(08)_F2.5-1

Figure 2.5-1 – System configuration (An example of mistakes in bonding)

Mitigation method/Results/Conclusion
As can be seen from Figure 2.5-1, the equipment is not installed according to the manufacturer's instructions. The idea of the manufacturer was that the equipment, provided with high-current inherent protection, would be earthed via the backside of the front panel to the installation frame that is further connected to the bonding system of the telecom centre. In the damaged system, however, the installation frame was painted with non-conducting paint, and this prevented the intended contact from the backside of the panel. Moreover, the manufacturer of the installation frame had installed the bonding bar of the frame on insulating supports, and although the installation personnel had connected the bar to the bonding system, the frame was not earthed. This example contains several general principles of problem solving methodology for the operator: • When a problem arises, react immediately. • Try to find the real reason of the problem by analysing the condition in the field and by laboratory testing. • Cooperate effectively with the manufacturer. • Check whether earthing instructions have been followed properly. • Check that the instructions are understood and taken into account throughout the country. • Arrange courses for installation personnel on practical problems and protection practices. It also shows one particular problem of bonding: paint may sometimes cause discontinuities.

References
Recs ITU-T K.27, ITU-T K.35, ITU-T K.40, ITU-T K.56; Annex C.

Case study #	2.6
Title	Lightning damage to a payphone
Type of trouble	Damage.
Source of trouble	Lightning.
System affected	Customer equipment (Payphone).
Location	Outdoors (in the street or in a campus).
Keywords	Damage, lightning surge, bonding, protection coordination, GDT.
Version date	2004-01-01

System configuration

The problem equipment is a payphone in an outdoor cabinet installed in a university campus. The earth for the mains supply to the payphone cabinet was tens of metres away from the cabinet. The local earth for the cabinet is 10s of ohms. Inside the cabinet is a double-insulated power supply which supplies 21 Va.c. to power the payphone. The payphone has a local earth for coin metering and lightning protection of the payphone electronics and users. Components were being physically damaged in the equipment. It was assumed that lightning was causing this damage. The system configuration is shown in Figure 2.6-1.

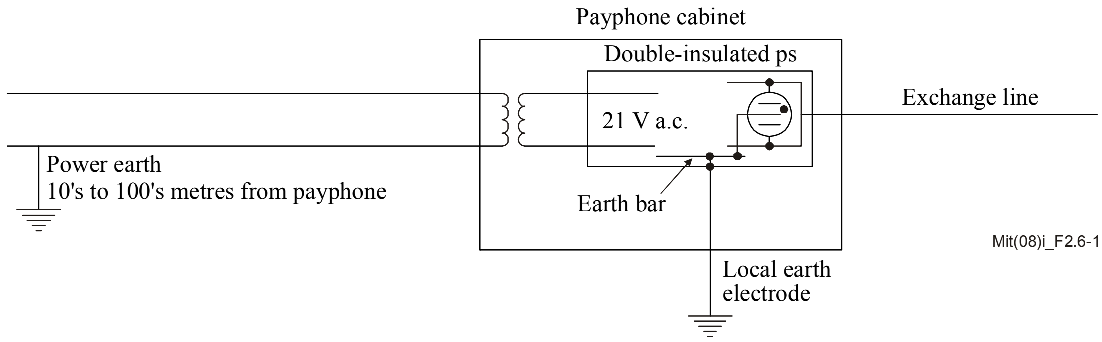


Figure 2.6-1 – System configuration

Measurement/Searching techniques/Experiment

The damaged components were identified by normal service technique. The dies of these components were then examined using both optical and electron microscopes. As recommended in Rec. ITU-T K.21, different types of lightning surges were applied to the payphone external conductors – i.e., the telephone line and the mains cable – in an attempt to replicate the damage. No damage could be caused at K.21-enhanced test levels.

It was then decided to inject surges into the low-voltage cable between the transformer and the electronics. This would not normally be done because the length of the cable between the transformer and the electronics is short and the cable is contained within a metal cabinet.

It was found that current limited 1.2/50 µs surges applied longitudinally to this low-voltage cable could reproduce the component damage as observed by a microscope.

The damage path was via the power supply port, damaged components and the internal telephone line protection circuit to the payphone earth. To prevent damage, bypass protection was added from the power supply input to the common earth point within the unit.

Mitigation method/Results/Conclusion
It is assumed that a lightning surge on the mains exceeds the breakdown voltage of the power supply transformer (8 kVd.c.) and injects current limited surges into the payphone 21 Va.c. power supply. This type of damage was not detected during testing of the mains input at 6 kV 10/700 µs (enhanced inherent mains port test).

The implemented solution is shown in Figure 2.6-2. A gas discharge tube (GDT) has been added to the low-voltage power connection to the electronics. This GDT is bonded to the frame earth, the same earth as the exchange line surge protective device (SPD), to reduce the level of stress which can occur between the low-voltage port and the telecommunication line port.

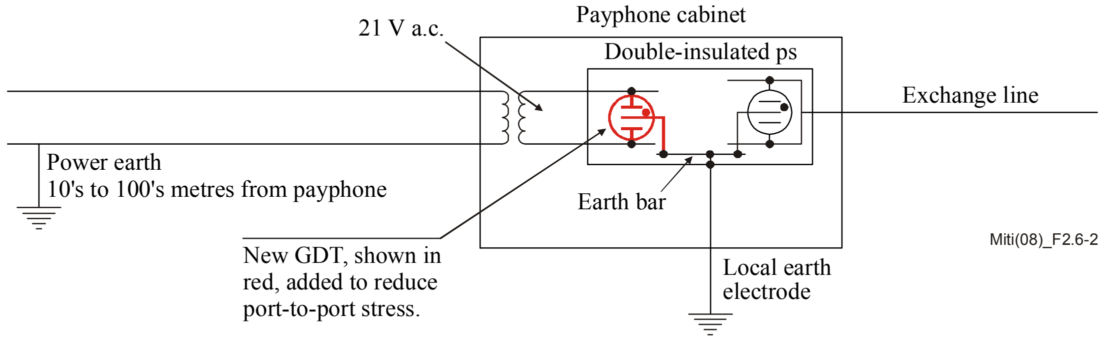


Figure 2.6-2 – Implemented solution

It is necessary to be careful when using a GDT on an a.c. circuit as it may not switch off after being triggered by a lightning surge. If the GDT continued to conduct a.c. current, the power supply and the payphone electronics could be damaged, due to overheating of the GDT. There are a number of ways to overcome the problem of the GDT conducting a.c. current:

- Use a special GDT for a.c. circuits.
- Use a positive temperature coefficient thermistor (PTC) or similar between the GDT and the transformer.
- Use an alternative mitigation technique.

An alternative solution is shown in Figure 2.6-3 below. The GDT does not conduct a.c. current in this case, due to the low voltage (21 V) involved.

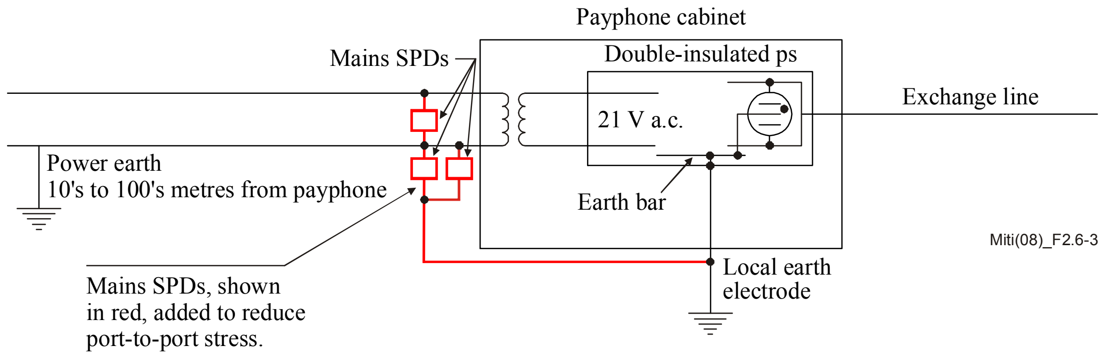


Figure 2.6-3 – Alternative solution

References
Recs ITU-T K.21 and ITU-T K.44.

Case study #	2.7
Title	Lightning damage to a telephone
Type of trouble	Damage.
Source of trouble	Lightning.
System affected	Customer equipment.
Location	Customer premises.
Keywords	Damage, lightning surge, inherent resistibility, GDT
Version date	2004-01-01

System configuration

The problem equipment is a telephone powered from the telecommunication line, in a customer premises. An integrated circuit (IC) in the phone was being physically damaged (impulse type damage). It was assumed that lightning was causing this damage and loss of function. Of the 50 customer premises investigated, half had primary protection and the other half did not. Most customers remembered a very close lightning strike.

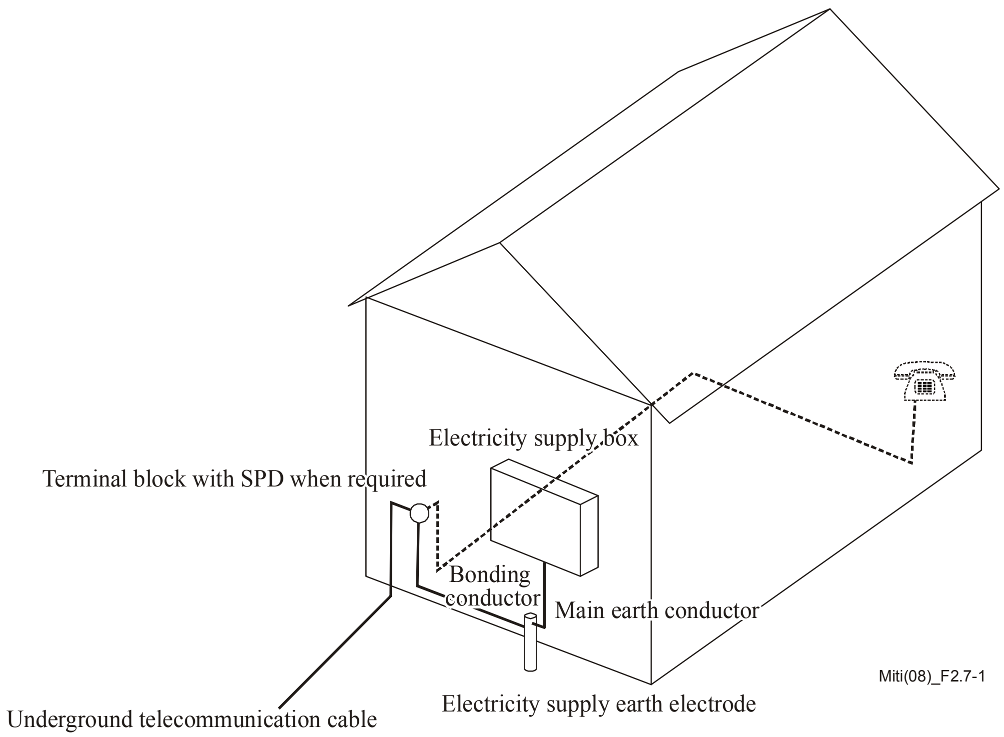
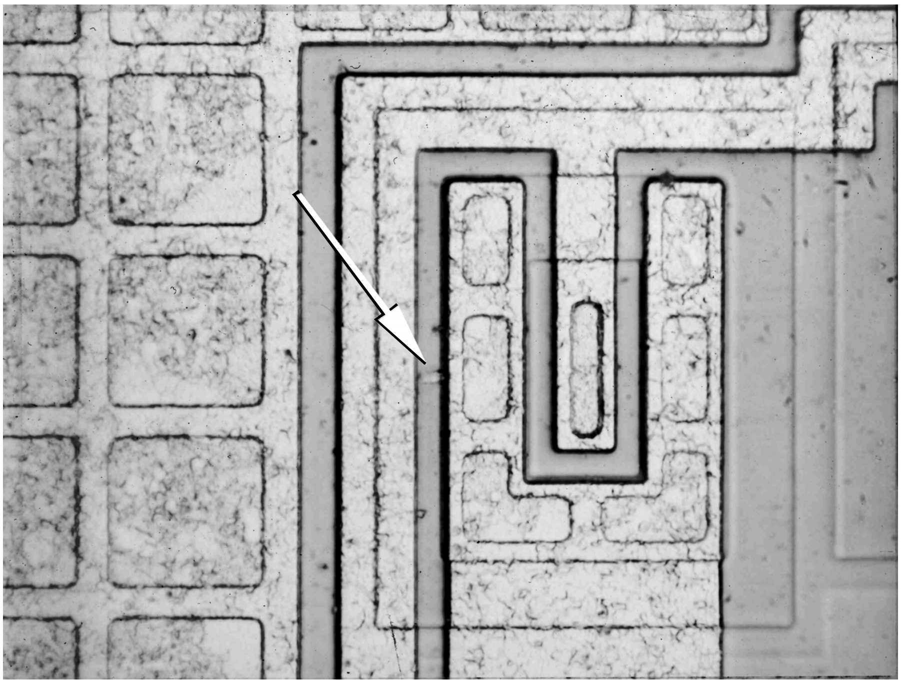


Figure 2.7-1 – System configuration

Measurement/Searching techniques/Experiment

Identifying failed components

The first part of the investigation was to identify the damaged components using normal service techniques. The component most damaged was a transmission IC. The plastic coating on top of the IC was then removed using chemical etching to expose the die. The die was then inspected using an optical microscope and photographed. Typical field damage can be seen in Figure 2.7-2.



Miti(08)_F2.7-2

Figure 2.7-2 – Damage to the transmission IC by lightning strikes

This damage is due to a breakdown between a conductor track and a ground as a result of an impulse overvoltage.

Replicating field damage in the laboratory

In an attempt to replicate this damage, different types of lightning surges, as recommended in Rec. ITU-T K.21, were applied to the telephone. No damage could be caused using up to 4 kV 10/700 µs waveshape, without external surge protective devices (SPDs), i.e., an inherent test voltage of 4 kV. When the voltage was further increased, damage could be caused but it was a different type of damage.

The next type of test was to investigate whether the operation of a GDT or sparkgap could cause a very high dV/dt and replicate damage to the IC. This test was performed with a GDT or sparkgap across the line or line to earth. Voltages as high as 6 kV could not damage the IC.

The next experiment was to check if high voltages (up to 100 kV) applied longitudinally could cause high charging currents and damage the IC due to the capacitance of the phone to earth. The charging currents did not cause damage but when one side of the line discharged to earth, the damage was replicated.

The current waveform of the current conducted transversely through the phone, when one side of the line breaks down, is as shown in Figure 2.7-3. This waveshape caused similar damage to the audio IC compared with field damaged ICs.

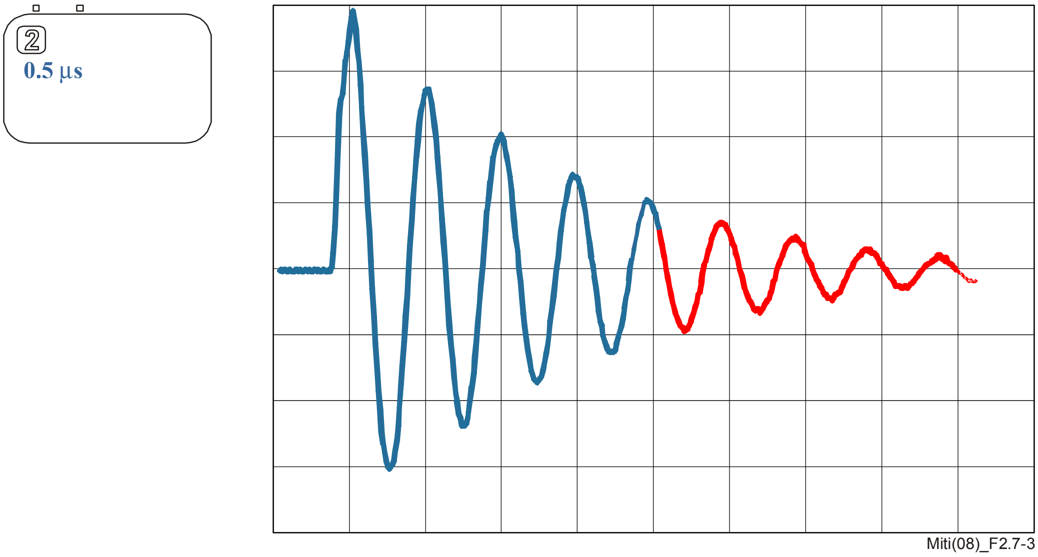


Figure 2.7-3 – Current waveshape entering the phone to replicate field damage

Increasing the resistibility of the phone

To "harden" the phone against damage, the current path from the line into the IC was identified from knowing the entry pins on the IC. The circuit was redesigned to minimize inductance of SPD lead lengths and components added to minimize the amount of current which could enter the IC. The inherent resistibility of the phone was increased fourfold from approximately 200 A to 800 A. Hardening the phone to this level eliminated damage to the phone, saving millions of dollars in maintenance per annum.

Unfortunately, while damage was no longer occurring, customers began complaining about stored number loss. Stored number loss was replicated by using the waveshape above but with a very high frequency oscillation added to the first half cycle.

The test generator used for the hardware damage test and the memory loss test is given in Figure 2.7-4.

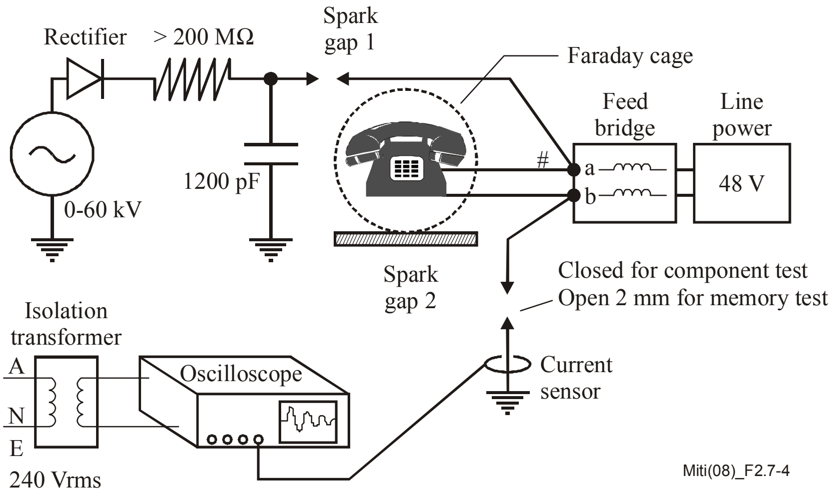


Figure 2.7-4 – Test generator for hardware damage and memory loss test

Lead lengths

The lead resistances and inductances are critical factors in determining the maximum current amplitude obtainable for a given generator source voltage and hence, the shorter the lengths (phone & earth) involved, the less source voltage required.

Test method

– *Hardware component test*: Spark gap 2 shall be closed. Spark gap 1 shall be opened to 1 mm. The voltage source for the generator shall be slowly increased until breakdown just occurs across Spark gap 1. The breakdown across the spark gap will be repeated as the capacitor recharges and discharges. The peak-to-peak current, of the first cycle, flowing to ground shall be measured and noted. The waveform shall be the same as the ringwave. The phone shall be subjected to 10 ringwave impulses before the telephone is tested for correct operation. Spark gap 1 shall then be opened in 1-mm steps and the process repeated until a peak current of 800 A is achieved. This is the current that the telephone is expected to resist without damage or misoperation. A new phone sample may be tested at this point to remove any deleterious combined effects of previous testing.

– *Memory retention test:* The opening of Spark gap 1 shall be adjusted to achieve a peak current of 400 A. It will be necessary to reduce the source voltage until a controlled discharge repetition rate is achieved. Once this current has been achieved, Spark gap 2 shall be opened to 2 mm. A minimum of 10 ring-wave impulses shall be performed on the telephone after which correct operation and memory retention shall be confirmed.

NOTE – The first half cycle of this ringwave will have a very high frequency ring wave superimposed on it. No attempt should be made to characterize this very high frequency ring wave as it would be exceeding the oscilloscope and current transformers operational performance parameters. Furthermore, it would require specialist measurement techniques, which are beyond the scope of this handbook.

Surge coupling
Because half of the services had GDTs installed, it is assumed that the coupling must have taken place between the phone and the GDT. Two methods have been thought of: – Induction into the internal cabling: This is thought unlikely as the surge is a transverse current requiring breakdown to ground of one side of the cable. This would require an induced voltage of tens of kilovolts. – Breakdown from earth to one side of the cable due to a high earth potential rise (EPR) due to a close ground strike: In Australia, indoor cabling is often tacked under the floor of the building and hence breakdown is possible.

Mitigation method/Results/Conclusion
The damage was solved by developing a test to replicate the field damage and by increasing the inherent resistibility of the phone fourfold. It should be noted that the original phone had an inherent resistibility of 4 kV 10/700 µs. Mitigation was very successful as the damage bill was dramatically reduced.

References
Recs ITU-T K.21 and ITU-T K.44

Case study #	2.8
Title	Earth wire voltage drop in telecommunication centre
Type of trouble	Damage.
Source of trouble	Lightning.
System affected	Transmission equipment.
Location	Telecommunication centre.
Keywords	Damage, lightning surge.
Version date	2004-01-01

System configuration

During thunderstorms, several line cards of a multiplex, located in a radio station, were frequently damaged.

Located on the top of a mountain, the radio station is composed of a 40-m high telecommunication tower and an adjacent 2-floor building (Figure 2.8-1). The antennas on the tower are connected to the radio equipment inside the building by wave-guide cables.

In the building, on the ground floor, there are the entrance of the low voltage power line through an insulation transformer, the power station, and the main earth terminal of the building. On the first floor, there is the radio equipment. On the second floor, there are radio equipment and a multiplex. The latter serves customers located close to the radio station.

The customers are connected to the multiplex by 30 pairs of 9/10 cable. This cable can be defined as a "lightning cable", i.e., the cable can resist high values of direct lightning current. Though it has been installed a long time, lightning never damaged the cable.

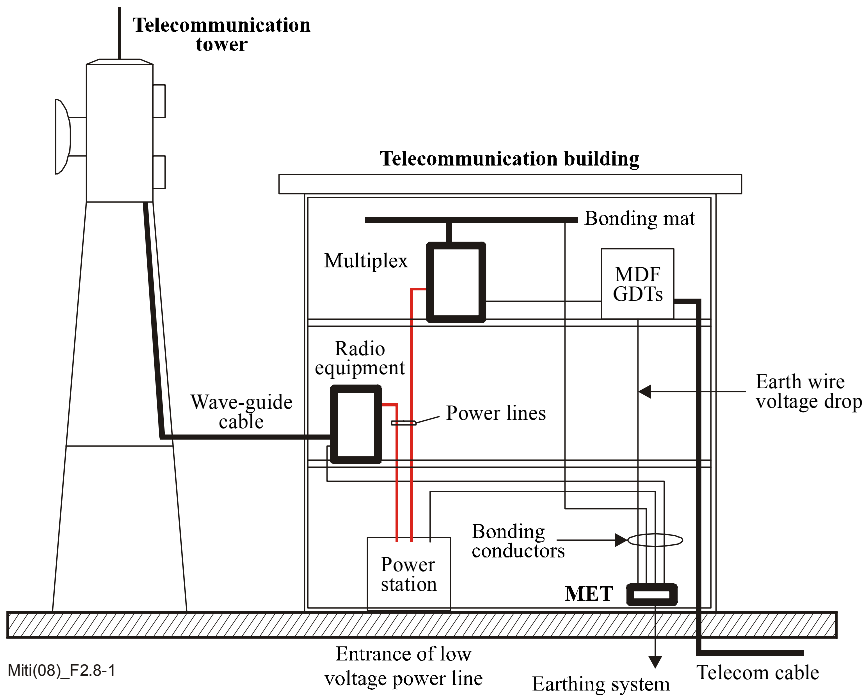


Figure 2.8-1 – Radio station

Measurement/Searching techniques/Experiment

An on-site survey was carried out. The survey results are as follows:

A small main distribution frame (MDF) is located on the second floor. Primary protectors, constituted by gas discharge tubes (GDTs), were installed at the MDF between all the cable conductors and the MDF metallic structure. The cable metallic sheath is also connected to the metallic structure of the MDF that is connected to the main earthing terminal (MET) on the ground floor by a bonding conductor.

The bonding mat, i.e., the ground plane, of the radio equipment and multiplex is also connected to the MET by another bonding conductor.

In this installation condition, when overvoltages cause GDTs firing, the voltage drop, caused by the overcurrents flowing in the bonding conductor between the MDF and the MET, will appear at the entrance of the line cards and could cause damages if its peak value is greater than the line card resistibility level defined by Rec. ITU-T K.45 or Rec. ITU-T K.20.

Mitigation method/Results/Conclusion

Because the earth wire voltage drop was probably the source of the line-card damages, the equipotential bonding technique was improved in order to prevent the earth wire voltage drop from being transferred to the equipment interface.

This was easily achieved by installing on the second floor another bonding bar (BB) connected to the MET. The metallic structure of the MDF (i.e., the GDTs' earth) and the bonding mat were directly connected to the second floor's bonding bar.

This installation avoids transferring the earth wire voltage drop to the equipment interface and there is no need to limit its value or to increase the line-card resistibility to lightning overvoltages.

Conclusion: The earth wire voltage drop is not a resistibility problem if equipotential bonding is properly achieved.

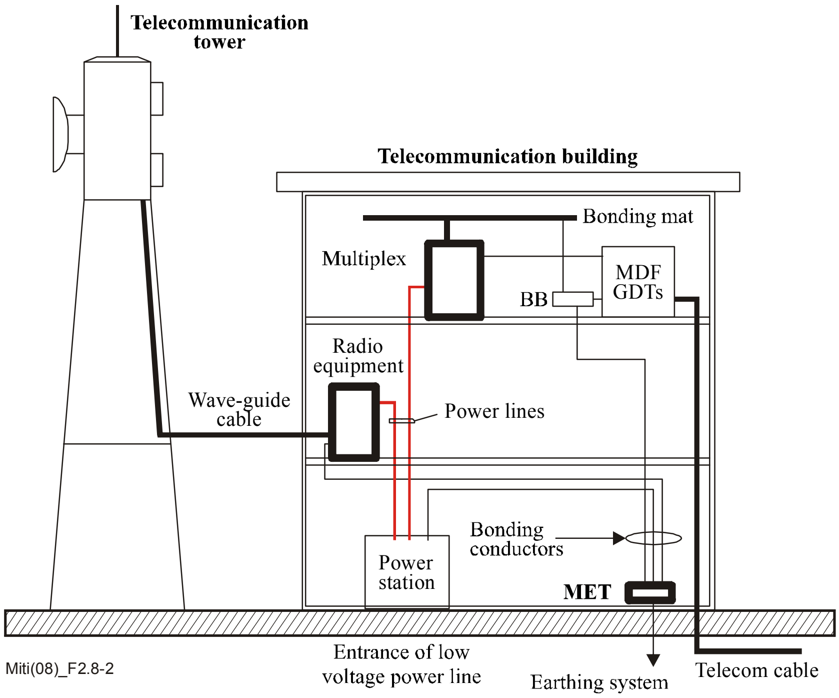


Figure 2.8-2 – New bonding configuration

Case study #	2.9
Title	Malfunction of circuit breaker due to lightning surges
Type of trouble	Abnormal operation.
Source of trouble	Lightning.
System affected	Access system.
Location	Outdoors.
Keywords	Safety, immunity, lightning, power transmission line, circuit breaker, MOV.
Version date	2004-01-01

System configuration

The circuit breakers in the power units of an access network system located outdoors malfunctioned due to lightning. The access network system had an optical fibre cable, which was connected to centre equipment, a metallic subscriber cable, and an AC mains line (Figure 2.9-1). The system had four power units. Each unit had a circuit breaker, with a capacitance of 5 A at the AC mains frequency. Figure 2.9-2 shows the system's protection circuits. The power units are produced by two manufacturers. Their circuits were almost the same, but they had different malfunction occurrence probabilities.

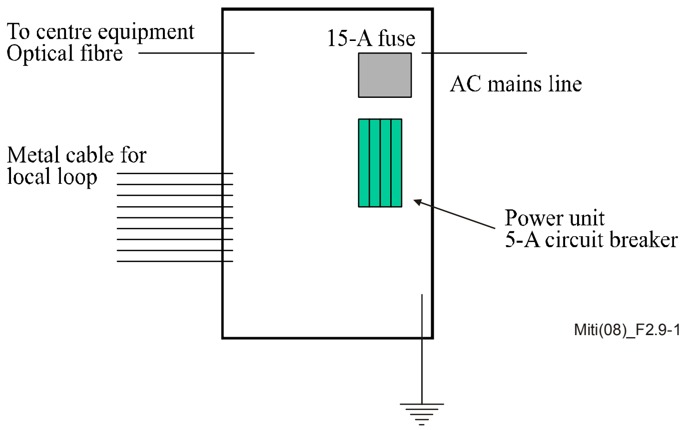


Figure 2.9-1 – Access network system

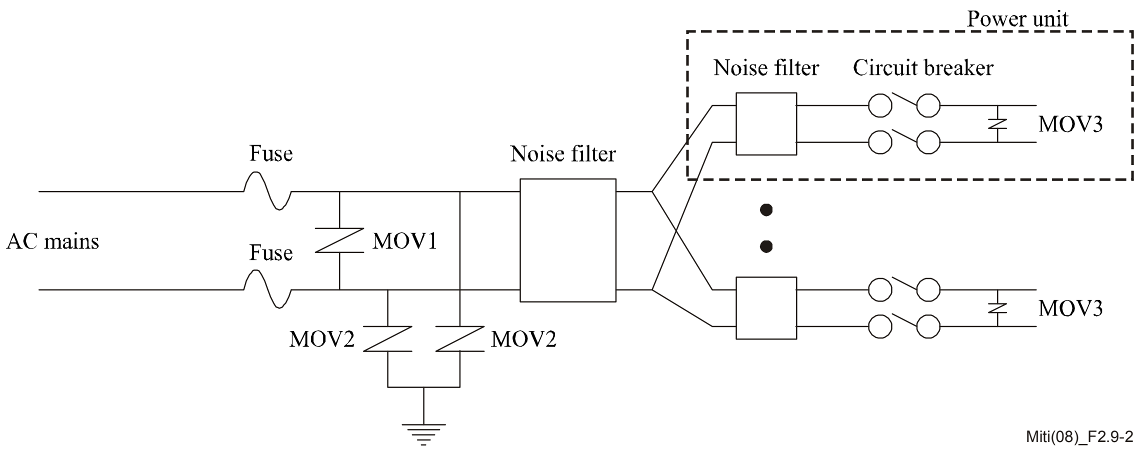


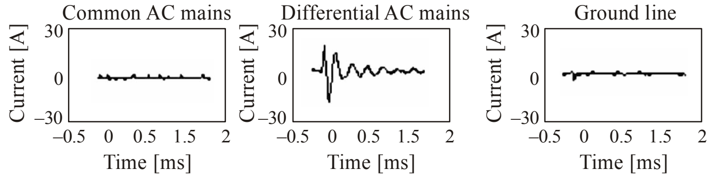
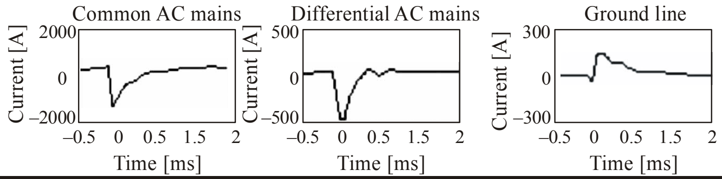
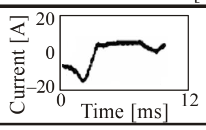
Figure 2.9-2 – Structure of overvoltage and overcurrent protection

Measurement/Experiment

1) Observation

The lightning surge currents in common mode and differential mode were observed in ten systems where failure often occurred. Two types of waveform and occurrence probability were obtained. The data are summarized in Table 2.9-1 and Figure 2.9-3. Malfunctions occurred with both waveforms. The peak current values were about 30 and 300 A, respectively.

Table 2.9-1 – Observed waveforms

Type of waveform		Characteristics of waveform
Lightning About 300 sets → 77%	Only differential mode appeared	
↓ 23%	Common and differential and ground appeared	
Other About 1200 sets	Only differential appeared	Peak current was 20 A. And the half-time value was from several milliseconds to several tens of milliseconds. 

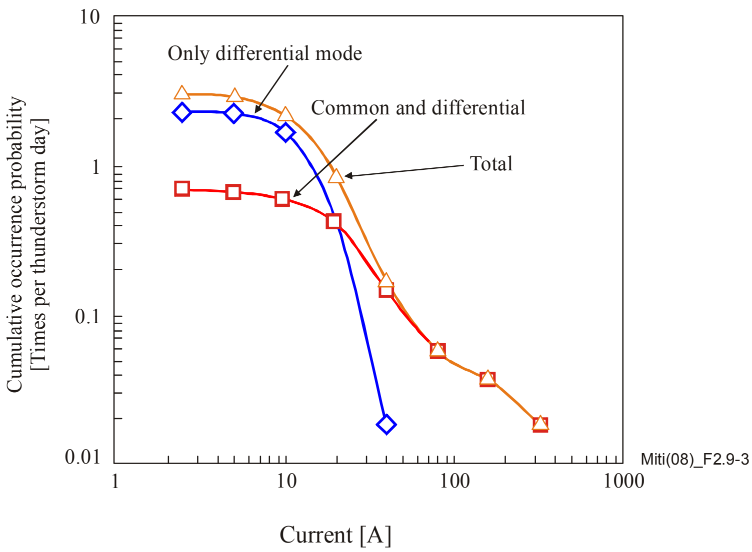


Figure 2.9-3 – Cumulative occurrence probability for differential mode current

2) Experiment

Noise immunity and lightning surge were tested. Malfunction did not occur in the immunity test. Also, several lightning surge generators (e.g., 10/700 ITU-T and 1.2/50 combination) and coupling/decoupling methods were tested (Figure 2.9-4). It was necessary to test the coupling and decoupling units to confirm the induced waveform and current value, which depended on them (Figure 2.9-5). The results are shown in Figure 2.9-6.

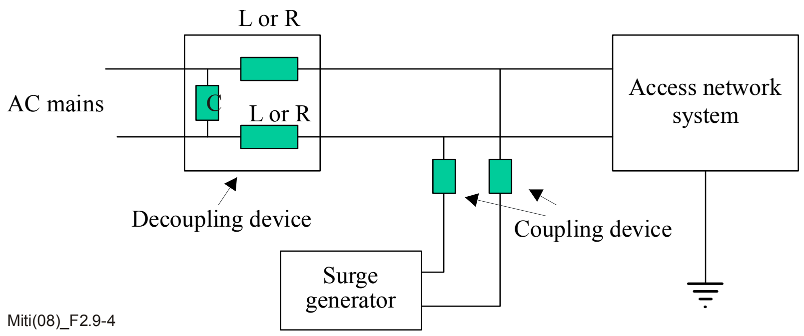


Figure 2.9-4 – Example of experimental set-up

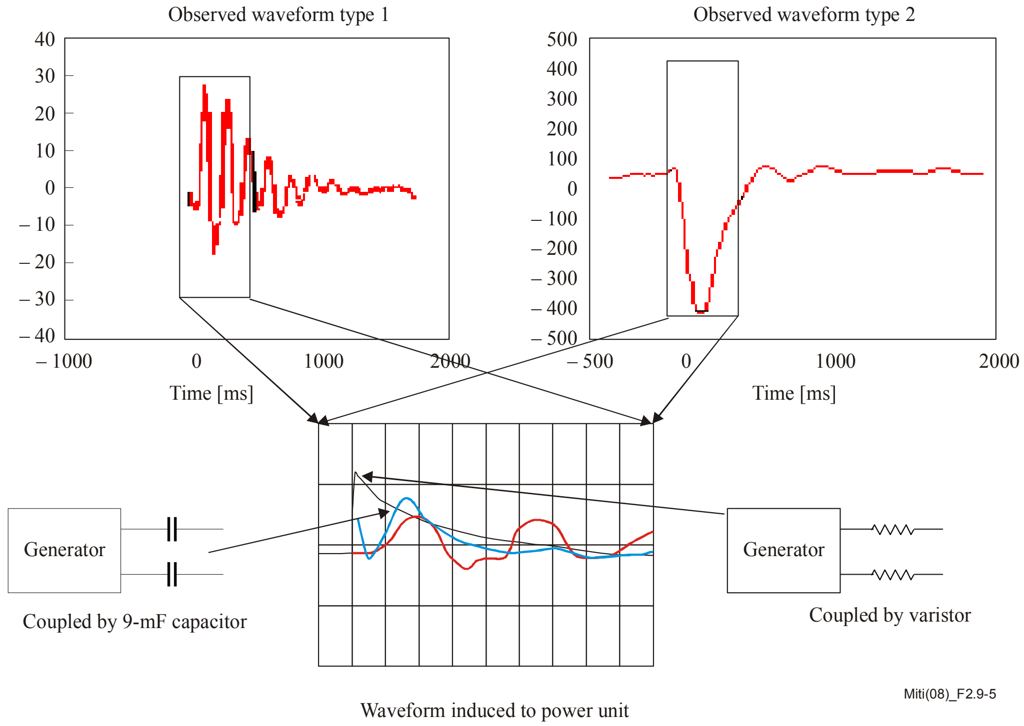


Figure 2.9-5 – Waveform difference by coupling methods

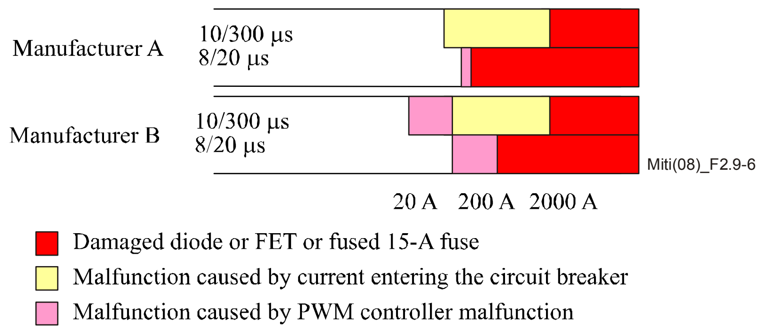


Figure 2.9-6 – Experimental results

Mitigation method

This malfunction was caused by two mechanisms. One was the lightning surge current flowing into the circuit breaker when MOV3 operated. In the field, the 15-A fuse did not break often, but the breaker did trip. The relationship between the lightning and operation time is shown in Figure 2.9-7. A new circuit breaker, whose characteristics at the AC mains frequency were the same, was developed and the response characteristics to lightning were improved.

The second mechanism was the malfunction of the pulse width modulator (PWM) controller, which has an overcurrent latch circuit consisting of a current transformer and filter circuits, as shown in Figure 2.9-8. The filter circuits (e.g., R114, R115, R34, RV1, C38) were from different manufacturers. In particular, R114 and R144 determine the sensitivity of CT1 and CT4, so their resistances were set smaller, and this improved the immunity level against lightning surges.

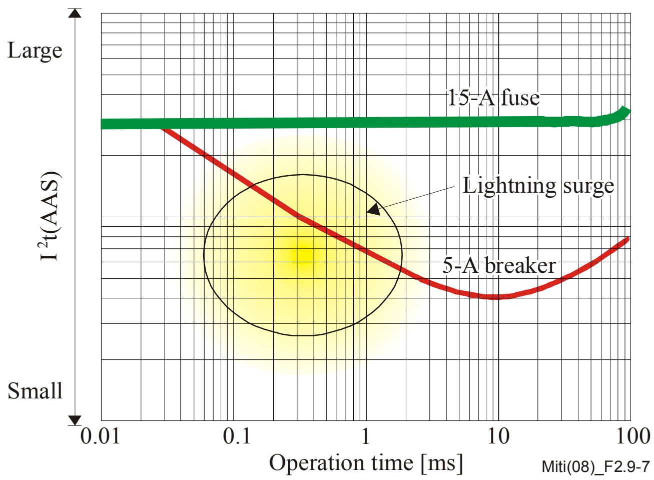


Figure 2.9-7 – Operation time and energy

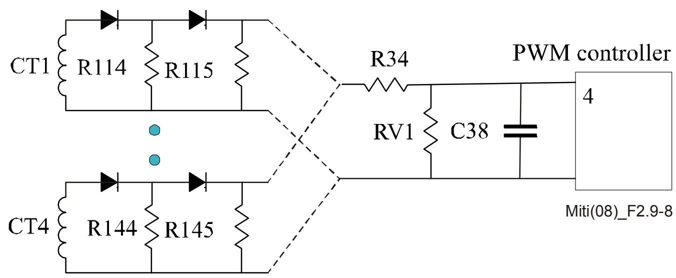


Figure 2.9-8 – PWM controller and filter

Case study #	2.10
Title	Protection of a wireless service connected to a few kilometres of copper cable
Type of trouble	Damage.
Source of trouble	Lightning.
System affected	Access switch.
Location	Outdoors (On a pole in a rural area).
Keywords	Damage, lightning surge, protection coordination, GDT, solid state overcurrent protection.
Version date	2004-01-01

System configuration

The antenna and the electronics containing the subscriber line interface circuit (SLIC) of a wireless service are normally mounted on the side of the customer's house or on a pole within a few metres of the house. In some installations, where the house is not in line of sight with the radio base station, the antenna and electronics may be installed a few kilometres from the house. When this type of installation is used in a lightning-prone area, lightning protection is installed to protect the electronics.

In this case, although gas discharge tubes (GDTs), and in some installations GDTs plus positive temperature coefficient (PTC) type overcurrent protection, were installed, lightning damage still occurred regularly (see Figure 2.10-1).

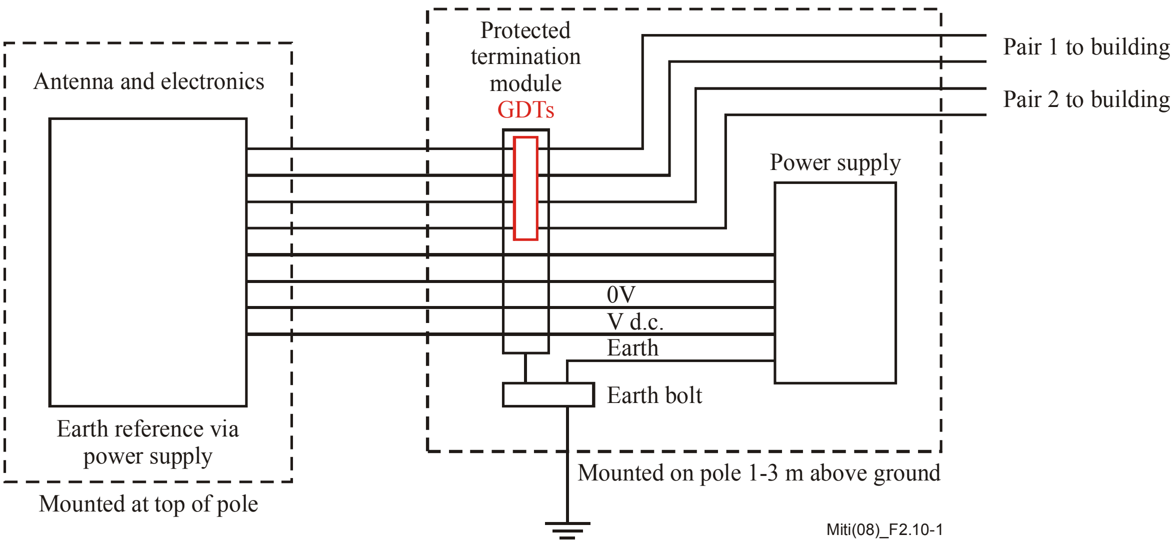


Figure 2.10-1 – Original system configuration

Measurement/Searching techniques/Experiment

Introduction

Damage was first identified in a couple of surface mounted diodes, see Figure 2.10-2 below, which are near the switch mode power supply connector.

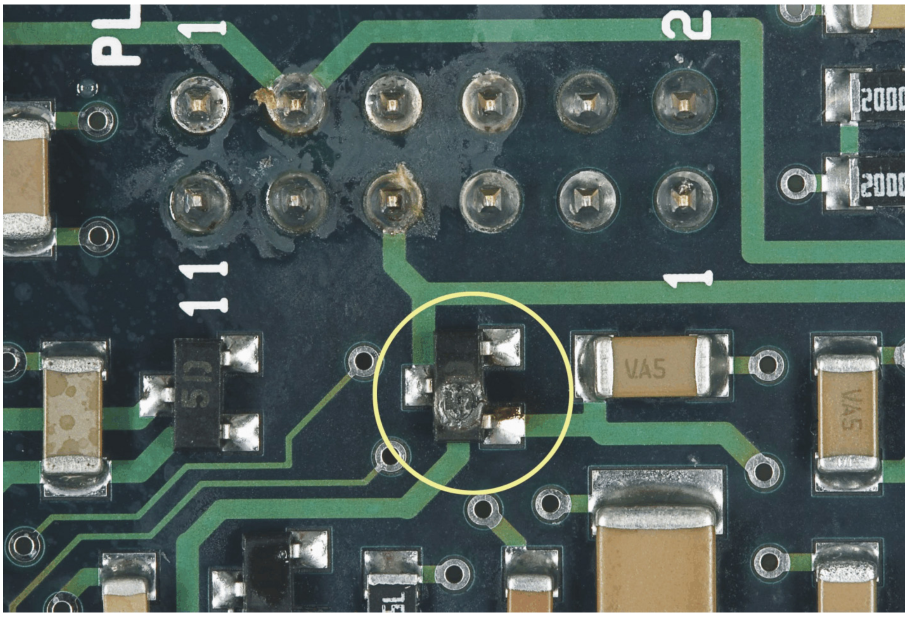


Figure 2.10-2 – Picture of damaged diode

Circuits, schematics and printed circuit board (PCB) layouts were obtained for this part of the system. This information, in combination with installation documentation, enabled a scenario for damage to be determined. It also identified components likely to be damaged. These components were:

- a thyristor protection circuit, which is a switching type protector and the first component on the printed circuit board where the line terminates;
- a diode which clamps the incoming line to the –70 V supply rail (line);
- a diode which clamps the incoming line to the –35 V rail (line);
- two diodes which connect from the –35 V and –70 V supply lines to the SLIC circuit. One of these diodes is shown damaged in Figure 2.10-2 above;
- the SLIC circuit.

Measurement/Searching techniques/Experiment

Investigation

The scenario is that a negative surge exceeding –70 V will drive the –70 V supply more negative due to current being conducted via the diode which clamps the incoming line to the –70 V supply rail. If the –70 V rail becomes too negative, it can cause semiconductor "latch up" of the SLIC. "Latch up" is a failure mechanism in semiconductor devices where externally applied transients exceeding the maximum supply voltage result in the triggering of internal parasitic transistors forming a thyristor-type structure. This internal thyristor can conduct appreciable current and typically results in the rapid destruction of the device.

The network operator investigated damage to the external thyristor protection circuit, to the diode which clamps the incoming line to the –70 V supply rail, and to the SLIC, by electrically characterizing these components and then de-encapsulating those components with degraded characteristics and inspecting them under an optical microscope. The SLIC showed signs of significant damage consistent with "latch up" indicating that the power supply was supplying current conducted to ground via the SLIC. The thyristor protection circuit had no signs of damage.

Surges were applied to a working circuit to verify this scenario. Figure 2.10-3 shows negative surges applied to an unprotected circuit. The generator surge (–191 V) causes a surge of –100 V on the b leg of the circuit. The difference of 91 V is due to the voltage drop on the coupling metal oxide varistor (MOV). The surge has caused the –70 V rail to be driven more negative (–70 V to –96 V). After a few surges, permanent damage has occurred.

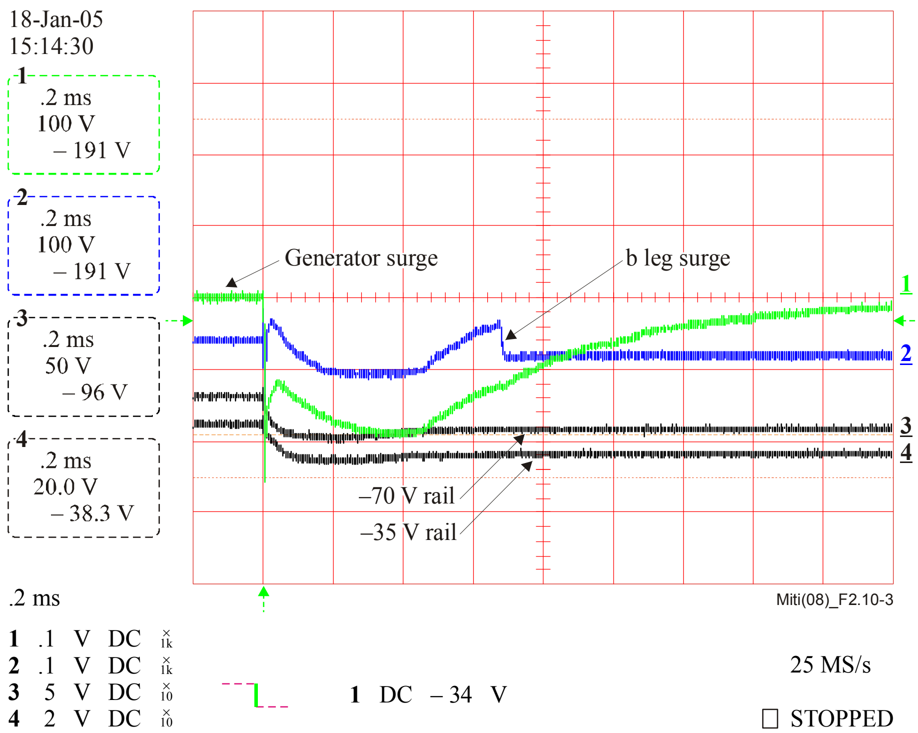


Figure 2.10-3 – Waveforms during a damaging surge

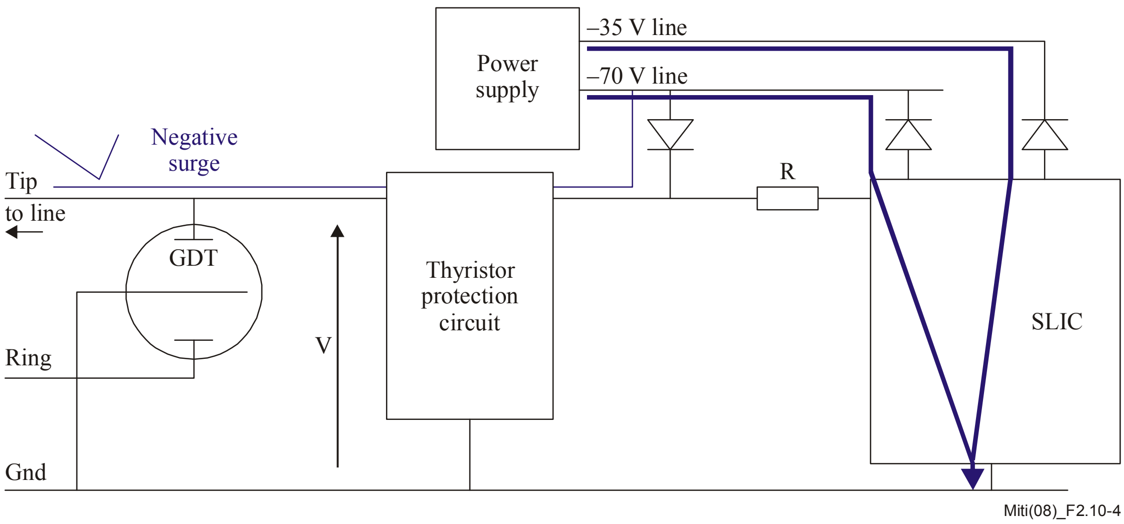
The failure appears to be caused by a negative surge entering under the firing voltage of the thyristor protection circuit (±190 V) and causing the –70 V and the –35 V rails to become more negative by the current entering the power supply via the diode which clamps the incoming line to the –70 V supply rail. When the –70 V rail is surged to approximately –100 V and the –35 V rail is surged to approximately –45 V, the SLIC latches up and the current is conducted from the –70 V and –35 V rails to ground, see Figure 2.10-4, which shows the current path through the thyristor protection circuit and the diode to –70 V, and the current from the –70 V and –35 V rails through the SLIC. It is the power supply current that damages the two diodes which connect from the –35 V and –70 V supply lines to the SLIC circuit (based on the fact that the diode which clamps the incoming line to the –70 V supply rail is not damaged).

The diode which clamps the incoming line to the –70 V supply rail was probably added to prevent the SLIC line inputs exceeding –70 V. However, adding this diode has resulted in rendering the thyristor protection circuit redundant and causing the SLIC to have its –70 V and –35 V ratings exceeded.

The scenario was confirmed by applying surges to a working circuit.

Measurement/Searching techniques/Experiment

Investigation



Magnitude of Voltage V less than required to operate either the thyristor protection circuit or the GDT.
Only part of the Tip side of the circuit is shown for simplicity.

Figure 2.10-4 – Simple circuit showing path of surge on tip side of line

Mitigation method/Results/Conclusion
As the equipment is being damaged by lightning surges of 10s of amperes, a fast acting overcurrent protector is required. A possible solution is to install a recently developed semiconductor overcurrent protector (SOP) (see Appendix II of ITU-T K.30 for details of this type of device) between the electronics and the GDT. This will limit the current entering the power supply to approximately 200 mA and prevent the –70 V and –35 V rails from being driven more negative. There may be other solutions, but they would involve a change to the circuit design or development of a custom external protector. This is unnecessary as a suitable device is available to fix the problem. Tests were performed on a working circuit in the test laboratory to check if the SOP device will protect the electronics. Figure 2.10-5 is a surge below the operating voltage of the GDT (–226 V at the GDT). The maximum voltage across the overcurrent protector is 158 V (226 V – 68 V). A negative surge pulls the b leg negatively until the diode connected to –70 V begins to conduct. As soon as the current through the SOP exceeds 200 mA, it operates and goes into a high resistance state. If the surge voltage is high enough, the GDT operates and protects the SOP.

Mitigation method/Results/Conclusion

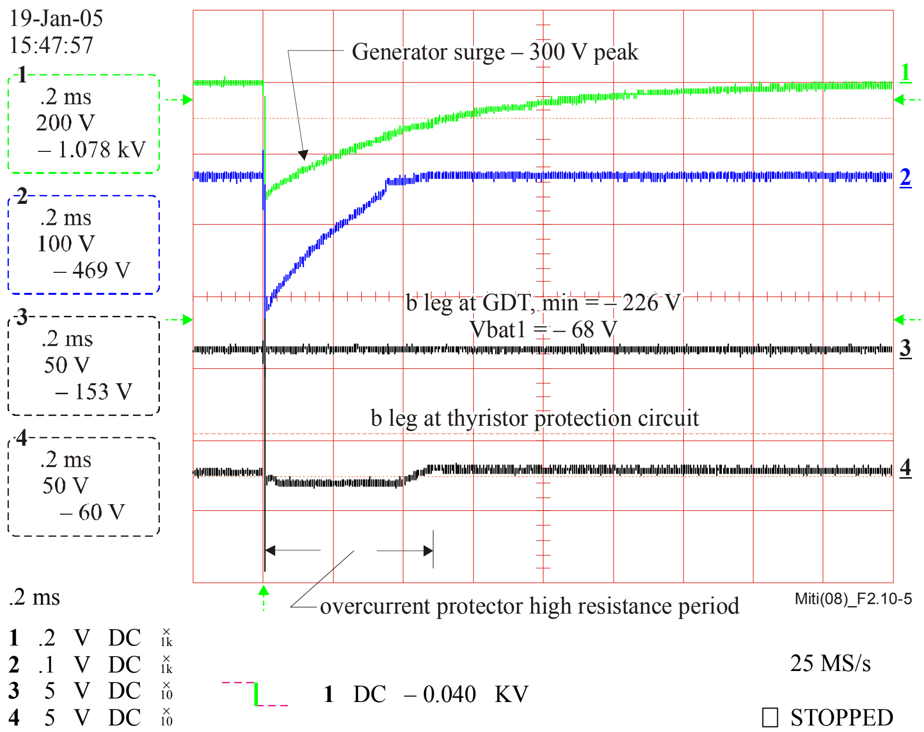


Figure 2.10-5 – Waveforms showing the semiconductor overcurrent protector blocking the surge

Tests performed indicate that the SOP will protect the circuit. Because the SOP limits the current to 200 mA, it prevents both the –35 V and the –70 V power supply voltages from being forced negatively. Figure 2.10-6 shows the new circuit configuration.

A field trial, where one of the two circuits was protected by a GDT and the SOP, has proved the success of the proposed protection. Within a few weeks of the installation, a lightning storm damaged the circuit protected by a GDT whereas the one protected by the combination of a GDT and the SOP continued to operate.

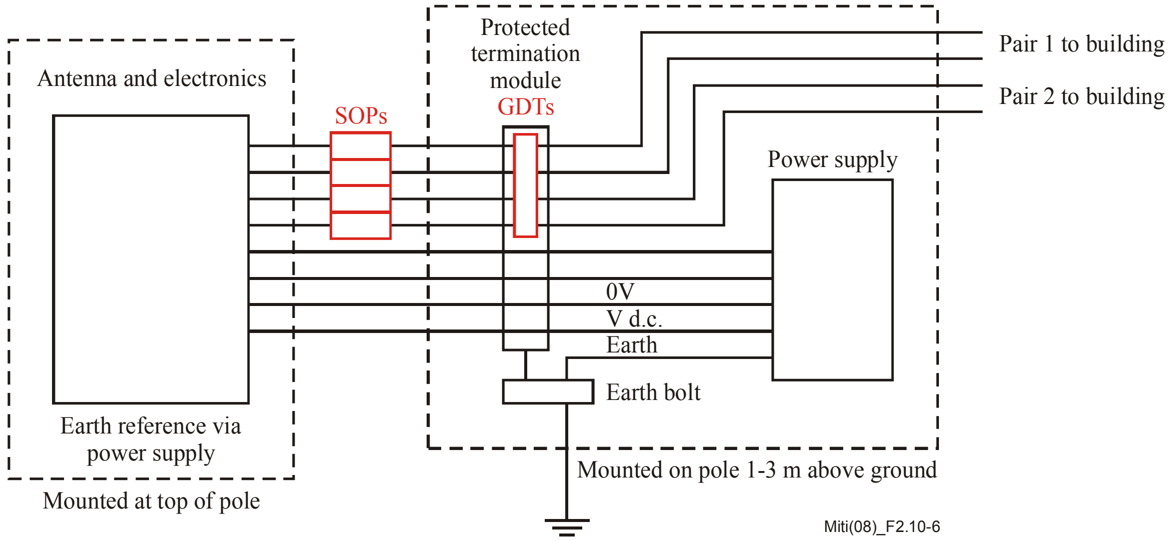


Figure 2.10-6 – GDT and SOP protected system

References
Rec. ITU-T K.30

Case study #	3.1
Title	Power and telecommunication systems grounding
Type of trouble	Abnormal operation, damage.
Source of trouble	Intermittently connected power neutral.
System affected	Customer's equipment – occasional continuous ring tone (no cadence) sometimes resulting in damaged customer apparatus.
Location	Customer premises.
Keywords	Safety, power transmission line, GDT, SPD, earth electrode
Version date	2004-01-01

System configurations

Normal PSTN line, isolated/exposed location on very high resistivity soil. Power feed and telecoms line to premises via aerial cables. The area was prone to lightning activity, and surge protective devices (SPDs) were fitted at the customers' premises to the telecom line (bonded to the power system earth).

Searching techniques

All measurements on the telephone line indicated that the line was well within specification and that there were no faults with it. The line-card at the exchange was replaced, just in case the fault was due to a 'sticky' relay or faulty subscriber line interface circuit (SLIC). The line was no better. Speaking with the customer revealed that the power to the premises appeared to fluctuate at times, sometimes just dimming, and other times going out completely for a few seconds. The power company had been asked to check the supply quality and claimed it was all OK. The last few instances of continuous ringing caused the SPD mains fail-safe to operate, resulting in an engineer call-out. The engineer put this down to lightning activity, but was later told that this was unlikely, so the investigation continued. Measurements of the earth electrode resistance at the customer premises revealed it to be higher than expected (note, the power supply necessitated that an earth electrode be used).

Mitigation method/Results/Conclusion

Due to the power fluctuations and the SPD going S/C, it was thought that the problem was likely to be due to system supply. The only possibility was if the neutral became temporarily disconnected, and as the earth electrode resistance was not particularly good, the return current route was via the telephone line.

As the power company could not immediately find any fault, the customer SPD was moved out of the premises, to a telecom pole about 25 m away, and a suitable earth electrode made. This still gave a good level of protection for lightning, and also removed the continuous ringing problem. The increase in resistance between the power earth and the telecom earth was enough to avoid the power return current flowing into the telecom line. Whilst the solution was not ideal (possibly giving rise to unwanted EPR during lightning) it has not resulted in any further damage due to the power of lightning. The power companies were informed of our findings and subsequently renewed part of the route.

References

Rec. ITU-T K.37, Annexes A and B.

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