Chapter 2: Review and Problem Definition

2.1 Review

Christos Christopoulos [1, p203] cited that effect of Electromagnetic Interference on a system depends upon the severity of the EM threat and the sensitivity of the system, which may lead to an upset or even damage of the system. For the effect of EMI, the behavior of a system can be altered to some degrees, but still may be acceptable to the users. Momentary malfunction of a system can be resulted from the effect of a burst of interference. Momentary malfunction may have catastrophic results, which cannot be tolerated in safety critical and mission critical system. Overwriting parts of a computer memory is a type of upset which is not immediately detrimental, but can create problem in future if left undetected and without rectification. Another type of problem which may be resulted from effect of interference is semiconductor damage, making the system incapable of functioning.

Jerry Gaboian [2] reported that "Electromagnetic Interference (EMI) can cause undesirable performance in a device or a system." He divides electronic equipments into two main EMI categories. The first category includes intentional radiation devices which emit radio frequency signals deliberately. Examples are - radio and television transmitters, citizen’s band and amateur radio transceivers, cellular telephones, radar and electronic navigation system etc. The second category includes unintentional radiators. Examples are - computers, home televisions and stereo sets, office equipments -such as printers, copiers, fax machines etc- fluorescent lights, power tools and power
lines. This second category is the cause of the most problems for systems, devices and designers.

Circuits with high impedance path are most susceptible to noise by capacitive coupling and inductive coupling mechanisms from nearby circuits. Unshielded twisted pair (UTP) wiring is more prone for noise pickup. This especially occurs if grounding system is inadequate or the cable is in close proximity to a noise source.

Most computer problems arise from electrical and magnetic causes. For example, computer monitor related problems are often caused by nearby magnetic fields, neutral wire harmonics or conducted / radiated electrical noise. Intermittent lock up of computers is another example of computer problem, which is very often caused by ground loops. Many problems may originate from an incorrectly wired or improperly grounded wall outlet also.

According to C.L. Wadhwa [3], generally communication lines run along the same route as the power lines. It is because the user of electrical energy also uses the communication system. The transmission lines with bulk power at relatively higher voltages give rise to Electromagnetic and Electrostatic fields of sufficient magnitude, causing induced currents and voltages respectively in the neighboring communication lines. The effects of these extraneous currents and voltages on communication system may interference with the communication service. The effect of these fields may so high that it may be impossible to transmit any message faithfully and may render the handling of the telephone
receiver extremely dangerous by rising the potential of the apparatus above the ground.

Larger the distance between the power conductors and the communication conductor, smaller is the value of mutual inductance between them. Again the current through the power conductors is displaced by 120°. Therefore, there is an appreciable amount of cancellation of the power frequency voltages. But the presence of harmonics and multiples of third harmonics will not cancel and since these harmonics come with audio frequency range, therefore are dangerous for the communication circuits.

References [4, 5, 6] also discuss the same problem of ref [2]. The power line may produce interference with the communication lines when they exist in close proximity due to electromagnetic and electrostatic induction. The electromagnetic induction may result in induced currents in the communication line, superimposing on the true speech currents in the communication line and causing distortion. The electrostatic induction raises the potential of the communication line and causes danger for both the equipment and the user. The effects of electromagnetic and electrostatic induction depend on the distance between the power and communication lines and also on the parallel route length of the power and communication lines.

To reduce the induced e.m.f. due to electromagnetic induction, the distance between the power and the communication line can be increased. If transposition of the communication line is done or if both the power and the communication lines are transposed, the induced e.m.f. becomes almost zero.
In reference [7, pp113,120], how electrical noise is transmitted into a single cable system is explained. Electrical noise is transmitted by the following ways:

- Galvanic (direct electrical contact)
- Electrostatic coupling
- Electromagnetic induction
- Radio frequency interference (RFI)

Galvanic noise can arise when two signal channels within a single data cable share the common return path or same reference conductor. It happens because the voltage drop caused by one channel’s signal in the reference conductor can appear as a noise in the other channel and can create interference.

Electrostatic noise is generated through various capacitances present in a system. Examples of such capacitances are: capacitance between wires within a cable, capacitances between power and signal cables, capacitances between wires to ground. Presence of these types of capacitances gives rise to low-impedance paths for noise voltages of high frequency and can create a disturbance in signal/data circuits.

Electromagnetic interference (EMI) is caused when a power conductor with a strong magnetic field is placed near other conductors. The flux lines of the strong magnetic field cut the nearby conductors and induce voltages on them. Presence of EMI can create noise in signal cables.
Radio frequency interference originates from coupling of noise by radio frequency.

Galvanic noise can be eliminated by not using a shared signal reference conductor. Electromagnetic induction can be minimized by putting the source of electromagnetic flux within a metallic enclosure or a magnetic screen. Use of a screen around the source restricts the flow of magnetic flux to go out. Use of such a screen around the receptor of EMI also, can reduce noise by not allowing the flux line to enter into it from the source of EMI. If the noise source and the receptor are physically separated, it reduces the magnetic coupling between them and therefore the interference. Another way to reduce EMI is to use twisted signal conductors. In twisted pair cables, for each twist along the length of the signal cable, the polarity of induced voltage will be reversed and will cancel out the noise voltage.

Electrostatic interference can be reduced to a minimum by the use of shields. Generally, shields are made of highly conductive materials. When a shield is placed around a signal conductor, the noise voltage which tries to flow across the capacitance between the signal conductor and say, power conductor, encounters the conducting shield. The shield is connected to ground, so noise voltage is diverted to ground through the shield instead of flowing through the signal conductor.

In reference [8, pp 365, 366] also how electromagnetic signals can couple from one device or circuit to another is described. When a circuit or some part of it shares a common path or impedance with another circuit, then current flow
and/or voltage fluctuations in the common impedance caused by first circuit produces a corresponding fluctuations or interference in the second circuit. If the common impedance is a conductor, then the resultant interference is called conducted *interference*. If the impedance is capacitive, then the interference is called capacitive or electric interference. Again, if the impedance is inductive, then the interference is called inductive or magnetic interference.

Interference between the two circuits can be generated even when the two circuits are not connected by a common impedance. This implies that interference between the two circuits is possible even when there is no physical connection between them. Here two cases may arise.

*Case1*: In this case, the two circuits are separated by a distance small compared to the wavelength of interest and coupling of signals from one to the other circuit occur by two ways (a) capacitive or purely electric type of coupling and (b) inductive or purely magnetic type of coupling. This type coupling is called *Near Field Coupling*. Here, the near zone E and H fields are involved separately.

*Case2*: In this case, the two circuits are separated by a large distance compared to the wavelength of interest and coupling of signals from one to the other circuit is purely electromagnetic. This type coupling is called *Far Field Coupling*. In this case, both the far zone E and H fields are responsible for the interference level.

Ashfaq Hussain [9, p 198] also discussed about the generated interference in a communication line from a power lines, when they run in close proximity.
The interference originates from the electromagnetic and electrostatic effects between them. Due to electromagnetic induction, a current is induced in the communication line which produces a distortion in speech signals. Again the potential of the communication conductors is raised due to electrostatic effects, which may be dangerous for both the equipment and personnel. To reduce the interference between power and communication lines, the distance between them is increased. Transposition of the conductors of power and communication lines also reduces the interference level if they run in close proximity.

S. N. Singh [10, p 251] also pointed out that “if the power line is running along the same route as the communication line, there will be an interference in the communication line due to both electromagnetic and electrostatic effects.” The electromagnetic effect produces currents, which is superimposed on the communication signal and thereby it is distorted. However, electrostatic effect induces voltage in communication line, which may be dangerous in handling the telephone receiver.

In reference [11], The Siemon Company concluded that “installing cabling without regard to sources of electromagnetic interference can be harmful to network performance and transmission quality”. The coupling between power lines and telecommunications cables occurs by the following mechanisms:

*Conductive coupling:* It occurs between power lines and telecommunications cable, when the bonding and grounding systems are not sufficiently separated.

*Capacitive coupling:* It occurs between parallel power lines and telecommunications cable through the capacitance between them.
Inductive coupling: It occurs between power lines and telecommunications cable through the mutual inductance between them.

Prevention of coupling mechanisms is done by either maintaining proper physical separation between power and telecommunications circuits or using screened or shielded cabling in installations where sufficient separation is not possible.

SHIELDING: Shielding protects telecommunications cabling systems from EMI. In shielding, a foil or braid surrounds the twisted pairs and the noise voltage is induced into it, instead of onto the conductors. There are two types of shielded cables: 1) ScTP (Screened Twisted Pair) cables, where twisted pairs are surrounded by an overall shield, 2) SSTP (Shielded Twisted Pair), where each pair is surrounded by a foil and also all pairs are surrounded by an overall shield.

PHYSICAL SEPARATION: A cabling system can be protected from EMI by ensuring some degree of physical separation between the telecommunications cabling lines, cross-connects, electrical power lines, distribution panels, secondary branch circuits and electrical office equipment. The Siemon Company has developed Table 2.1 and Table 2.2 for the minimum distance recommended for both 100 ohm UTP and ScTP cabling, as well as the pathways and spaces.
Table 2.1: Minimum power separation for UTP cabling systems

<table>
<thead>
<tr>
<th>Power Level</th>
<th>&lt;3kVA</th>
<th>&gt;3&lt;6kVA</th>
<th>&gt;6kVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathways</td>
<td>50mm (2in)</td>
<td>1.5m (5ft)</td>
<td>3m (10ft)</td>
</tr>
<tr>
<td>Spaces</td>
<td>50mm (2in)</td>
<td>3m (10ft)</td>
<td>6m (20ft)</td>
</tr>
</tbody>
</table>

Table 2.2: Minimum power separation for screened and shielded cabling systems

<table>
<thead>
<tr>
<th>Power Level</th>
<th>&lt;3kVA</th>
<th>&gt;3&lt;6kVA</th>
<th>&gt;6kVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathways</td>
<td>0m (0in)</td>
<td>0.6m (2 ft)</td>
<td>1m (3 ft)</td>
</tr>
<tr>
<td>Spaces</td>
<td>0m (0in)</td>
<td>0.6 m (2ft)</td>
<td>1m (3 ft)</td>
</tr>
</tbody>
</table>

The Siemon Company recommends UTP cabling as the preferred cabling media in situations where proper physical separation can be maintained. In situations, where minimum separation for UTP cabling cannot maintain, ScTP or SSTP cables are advised to use.

In reference [12], it is pointed out that “Shielded cables were designed mainly to withstand sources powerful enough to generate a field of electromagnetic interference or EMI.” In modern day building structures, different types of lighting, generators and elevator motors within the building are the examples of some powerful EMI sources. The EMI from these sources can pass through the cabling system very easily and the transmission of data may be affected, which may result in shut down of the communication system. It is not always possible to avoid data transmission cables from running close to these types of EMI sources. In that case, it is better to use shielded cables.
In [13], it is found that during installation of communication cabling, the communication cabling should be installed keeping some distance away from power cabling to avoid interference pickup from power cables. The communication cables should be kept at least 15 cm away from 230V AC lines and 20 cm away from 400V AC lines, at the time of installation.

Frank J. Derfler,Jr [14] discussed about the electrical signals on LAN cables. They are electrical square waves representing binary 0s and 1s. This signaling scheme works well for the transmission of data, but it faces two problems: one is radiation and the other is interference. Different networking cables take different ways to tackle these problems.

The problem of radiation originates from the infinite harmonics generated by the rising and falling voltages of the square waves. The second problem is interference, which comes from outside noise sources. Undesired electrical signals from motors, power lines, fluorescent lights, radio transmitters and many other sources can disrupt the desired signals on the LAN cable, which may result in loss of original data. Therefore, LAN cables should be protected against the undesired signals causing disruption from outside electrical interference source. Same techniques are used to reduce the incoming interference, which are used to stop unwanted radiation.

Robert Y. Faber Jr., RCDD and Valerie A. Rybinski [15] reported that the ‘National Electrical Code’ specifies a ‘2 inch’ separation between communication cabling and conductors of any electric light or power supply. To demonstrate the sensitivity of UTP cabling to common sources of EMI, they
conducted an experiment for ‘generic’ category 5 and ‘enhanced’ category 5 UTP cabling by exposing to various sources of noise such as electric hand drill, Transceiver set, Fluorescent light, Microwave oven etc. Signal packets and network traffic were monitored for errors using a commercially available LAN analyzer software program. Sensitivity was determined by evaluating the number of packet errors detected under peak operating Network utilization. Result was “no packet error were detected for either the ‘generic’ or ‘enhanced’ category 5 channel configuration regardless of EMI source type, source location or duration of exposure.”

In ref [16] Keith Lane illustrated with examples the required separation gap between power cable and UTP cable using Siemon model. He concluded in his article that “installing cabling with no consideration of potential sources of EMI can be harmful to network systems performance and data transmission quality”. He pointed out two main sources for a designer or engineer to identify the appropriate separation between the electrical and data systems. The two main sources are National Electrical Code (NEC) and BICSI’S Telecommunication Distribution Methods Manual (TDMN). The TDMN references standards from ANSI, TIA and EIA.

ANSI/TIA/EIA-569-A [17] indicates that co-installations of telecommunication cable and power cable are governed by applicable electrical code for safety. Additionally, there are some precautions also, which should be considered in order to reduce noise coupling from sources such as electrical power wiring, radio frequency (RF) sources, large motors and generators, induction heaters and arc welders:
• Increased separation distance

• Electrical branch circuit line, neutral and grounding conductors should be maintained close together (e.g. twisted, sheathed, taped or bundled together) for minimizing induction coupling into telecommunication cabling.

• Use of surge protectors in branch circuits can further limit the propagation of electrical surges.

• Use of fully enclosed, grounded metallic raceway or grounded conduit or use of cable installed close to a grounded metallic surface will also limit inductive noise coupling.

Ref [18] states that the Electrical Safety aspect is described in the National Electrical Code (NEC) (ANSI/NFPA 70) or other locally approved electrical safety codes. The separation between power and network cabling is described in the NEC Article 800-52 “Installation of Communication Wires, Cables and Equipment”. NEC specifies the following: “Communication wires and cables shall be separated at least 50mm (2in) from conductors of any electric, power, class 1, nonpower-limited fire alarm, or medium power network powered broadband communication circuits.” There are two exceptions, those are noted in the NEC:

*Exception #1: Where either (1) all of the conductors of the electrical light, power, class 1, nonpower limited fire alarm and medium power network powered broadband communication circuits are in a raceway or in metal sheathed, metal clad, nonmetallic sheathed, type AC, or type UF cables, or (2) all the conductors of communications cables are encased in raceway.*
Exception #2: Where the communication wires and cables are permanently separated from the conductors of electrical light, power, class 1, nonpower limited fire alarm and medium power network powered broadband communication circuits by a continuous and firmly fixed nonconductor such as porcelain tubes or flexible tubing, in addition to the insulation on the wire.

NEC is primarily written for safety purposes, it is not written for the recommendations for optimum performance of communication systems. The 50.8mm (2in) separation between power cable and communication cable should not be viewed for the performance issues of the sensitive data systems, it should be viewed as a safety issue only.

Ref [19] states “Separation between SCS structured Cabling and Power Systems should be as large as possible, but available space will always be a limiting factor.” All network equipments, controllers and cabling are needed to be placed as far as possible from noisy electrical circuits, such as lifts, air handling units, chillers, variable speed motors, switched loads, relays etc. Proper grounding and lighting protection play an important role to provide a stable power supply within a building structure. Power supplies of a building structure can suffer from different types of problems, such as RF noise, harmonics, transient over-voltages, dips, surges, frequency variations, RMS fluctuations and fluctuations. Change of voltage or current will create an induced voltage on any adjacent signal (data/voice) resulting in data corruption in data/ LAN cables and line noise in voice circuits. The above cited ref also pointed out that the criteria for maximum induced longitudinal voltage into SCS UTP cabling from one or more cables is 50mV(0.050V) under normal power
cable operating conditions. The induced voltage from more than one power cable is added in phase.

Ref [20], concluded with that “for personal safety, we should follow all local codes, safety guidelines and practices when installing telecommunication cables in or around the vicinity of power supply cables.” Installation of communication cabling inside buildings should be considered with special planning to avoid EMI. Installing cabling without regard to potential sources of EMI may be harmful to a network system resulting in poor data transmission quality. Proper routing, shielding, barriers and use of optical fiber (immune to EMI) can help to reduce the effect of EMI. Shielded twisted-pair (STP) and Screened twisted-pair cables can be used to protect against EMI.

2.2 Problem Definition

Interference or noise is defined as unexpected electrical signals, which interfere or distort with an original signal. When noise is generated from within the system itself, it is called internal noise and when generated from an outside source, it is called external noise. Electromagnetic Interference (EMI) is one type of external noise [21, p 102].

Effect of Electromagnetic Interference (EMI), is becoming an exceptionally crucial issue in the design of electronic and electric systems. Electromagnetic Interference (EMI) is an undesirable phenomenon, which creates electromagnetic disturbance in the response of electrical or electronic equipment. EMI degrades the performance of a system due to the electromagnetic fields making up the electromagnetic environment.
Electromagnetic environment is the totality of electromagnetic interference phenomenon present at a given location [22].

Designing and Installing UTP cabling infrastructure without regard to EMI can be detrimental to Network Performance and Signal Transmission Quality. In a LAN system, when the networking cable comes to the close proximity of the electromagnetic field of an AC power line, unwanted current and voltage may be induced on it. If the electromagnetic field is strong enough, the induced voltage and current can create electrical noise which may interfere with both the voice and data applications running on the cabling. In data communication, successful detection of data packets by the receivers may be difficult for excessive electromagnetic effect (EMI), which may result in increased errors, network traffic due to packet retransmissions and network congestion.

UTP cable, the most popular and dominant cable supporting Ten Gigabit Ethernet standard, is also the mostly effected cable by EMI among all types of copper based cable. The coupling between UTP cable and Power line (a source of EMI) occurs by three mechanisms: Conductive, Capacitive and Inductive couplings [11]. The Table 2.3 shows different types of cables and effects of EMI on them.
In ref [23], it is mentioned that “UTP cables rely solely on the cancellation effect produced by the twisted wire pairs to limit signal degradation caused by electromagnetic interference (EMI) and radio frequency interference”. It is also mentioned that “for further reduction of crosstalk between the pairs in UTP cables, the number of twists in the wire pairs varies”. A Twisted Pair (TP) consists of two copper wires, twisted together. When electric current flows through a copper wire, a small circular magnetic field is created around the wire. When two current carrying wires of an electrical circuit are in close proximity, the two magnetic fields are the exact opposite of each other. Hence they cancel each other out. They also cancel out any outside magnetic fields. This cancellation effect is enhanced when the two wires are twisted. Cable designers provide a self-shielding technique against signal noise and cross-talk for wire pairs using the cancellation effects together with twisting the wires.
The Siemon Company, the Network Cabling Solutions Supplier, have pointed out that installing UTP cable without regard to EMI can affect the performance quality of structured cabling systems [11]. According to Siemon Company, there are two effective methods to minimize the effect of EMI on UTP cablings:

1. Physical Separation
2. Use of Shielding

By maintaining some degree of physical separation between power lines and UTP cable, the cabling system can be protected against EMI. The Siemon Company, specify the minimum distance recommended for 100 ohm UTP cabling, as well as the pathways and spaces used to carry or house the telecommunications cabling. These distances have been provided by The Siemon Company to assist in reducing the effect of EMI on cabling systems and are not intended to be used in place of local codes and regulations. By applying the proper physical separation distances, UTP cabling can be used in a cabling system, while still avoiding EMI. In fact, in situations where proper physical separation can be maintained, The Siemon Company recommends UTP cabling as the preferred media. In situations, where minimum separation distances cannot be maintained for UTP cabling, ScTP or SSTP cable can be used.

Installing cabling without regard to sources of EMI can be detrimental to network performance and transmission quality. When installing UTP cabling, the cabling should be installed maintaining proper physical distance from power cabling to avoid interference pick up from power cables to LAN wiring. Power
cables and LAN wiring should never be installed inside same electrical wiring pipe for both safety and interference reasons. Although this is being practiced in networking, a well accepted standard is not yet available. Many suggestions are available in literatures and documents. A widely accepted convention [13] is that when installing cables, the communication cables should be kept at least 15cm away from 230VAC lines and 20cm away from 400VAC lines. In ref [15], the ‘National Electrical Code’ specifies “2 inch” separation between communication cabling and conductors of any electric light or power supply. By applying the proper physical separation distances, UTP cabling can be used in a cabling system, while still avoiding EMI. In fact, in situations where proper physical separation can be maintained, The Siemon Company [11] recommends UTP cabling as the preferred media. In situations, where minimum separation distances cannot be maintained for UTP cabling, it is advised to use ScTP or SSTP cable. The Siemon Company, specify the minimum power separation for UTP cabling systems for power level less than 3KVA as 50mm (2 in).

The present study has been trying to carry out an extensive study and experimental analysis on the effects of AC power cables on adjacent UTP cables. For this, theoretical in depth study of the subject matter related to the work has been carried out and tried to define electromagnetic interference with mathematical model. An experimental setup has prepared, consisting of UTP cabling structure and AC power lines. Experiments with real time measurement has been done by maintaining different physical distances between UTP cable and AC power lines with variable loads. Parameter values such as signal
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voltage, distance are captured. After that, analysis has been done considering signal voltage variations.

References


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