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Modeling of Power Line for Home-Building Automation

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***Abstract*— The purpose of this research is to investigate the viability of wired technologies for home-building automation and to put up a simpler transfer attribute prototype for the low voltage power line for effective information exchange based on the two-wire transmission line hypothesis. Software based simulation is done to check effect of length parameters. In the investigation for viability, a bottom-up approach is used for parameters and scattering matrix is applied in frequency-domain for channel prototyping.**

Keywords—Power Line Channel, Two-Wire Prototype, Access Network, Home-Building Automation

I. INTRODUCTION

21st century is an age of information technology; therefore, major concentration is on creation and utilization of information. In order to deliver the information to the end users, communication networks and service providers are needed. Therefore, restructuring and regulation of telecommunication market has been started. After the regulation of the telecommunication market all over the world, access networks have been the property of public companies. The private operators that are new in the market are building their transport networks, yet they are bound to use the access set up of a public company. For this reason, the new network operators are looking for ways to offer their subscribers their own access network. At the same time, the very fast development of telecommunication technologies has increased the urge for increased transmission capability in transport networks and in access area [1]. Thus, there is an everlasting demand to expand the access infrastructure. The extension of an access network involves the fulfillment of any one obligation: construction of new networks or the handling of the in-existence infrastructure.

Construction of futuristic networks for access is tedious and is not cost effective as it involves installation of fresh cables or optics and multiple wireless transmission arrangements must be integrated in the area of access. The implementation of wireless systems in the access networks is costly until now. Moreover, porting of substantially sized networks having wireless systems need excessive devices which increases the network cost and data rates are considerably inferior to that obtained in optical networks.

The in-existence set up for the operation of the access networks are telephone networks, Cable TV (CATV) networks and electrical power supply networks. Telephone networks generally belong to monopolistic companies [2] which is a big drawback and CATV networks must be competent to transmit the data in both directions, which adds costs. On this basis, selecting electrical supply networks for exchange of information appears to be a rational answer to the problem of finding a more efficient alternate to the conventional means available. Nevertheless, in order to compete with other available technologies, power line communication must be an economically feasible alternative and it must provide a great opportunity for a high-quality telecommunication service.

The merits of putting this rising technology into practice are noteworthy, like installing a time taking and costly infrastructure is not at all required. Also, power line communication techniques seem more pleasing due to utilization of only the existing network of wires in the line [3]. The use of electrical power lines as a means of data transmission has the advantage that each building and house has power lines already that are connected to the mains.

A latest technique based on computer software, described here, to characterize the home-building power line channel, has been explored. In this paper, a frequency domain prototyping-based bottom-up approach utilizing a scattering matrix is put into effect in a similar manner as in [4]. Nonetheless, a two-wire line prototype is used without the influence of the third conductor because the conductors concerned are only those which are used for the propagation of signal i.e. the "live" and "return" conductors.

Furthermore, the important facts which are missing in the paper [4] and in other studies that the equations used to determine the primary line variables R, L, C and G are applicable only to low frequency conditions and when the separation between the conductors is much larger than the radius of the conductors, while in a network of home-building power lines, the conductors are just routed through the pipes, the spacing between the conductors is very less and the technology works at radio frequencies of MHz range.

Section II contains a general description of the communication over power lines for home automation, using an example of home-building automation. This section also describes that how communication over power lines can be integrated into the in-existence set up. A two-wire transmission line equivalent circuit-based home-building power line analysis is described in Section III. In Section IV, the modeling concept for a power line and its parameters have been discussed. The determination of transfer function characteristics and the effect of line length realized with the help of a simulation software is described in Section V. A

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holistic view of the feasibility of power line communication for home-building automation is discussed in Section VI.

II. HOME-BUILDING AUTOMATION

In Section I, few terms are used very often that is transport network, distribution network and access network. These terms are explained using diagram shown in Fig.1. Home and other local area networks lie under access area network, that will be explained in this section.

In-home power line communication uses electric structure within the house as a means of communication. It allows the operation of local networks within the houses, which connect with the devices that are already present in houses and buildings [5].

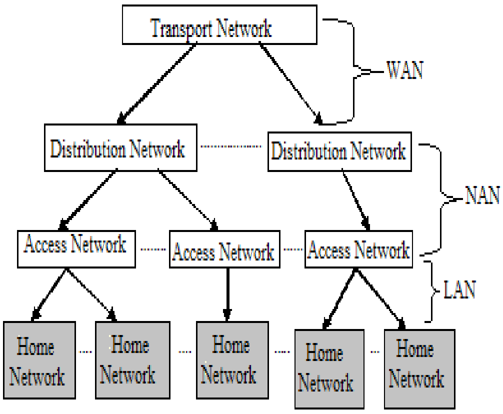

Fig.1. Communication networks

Automation services are getting increasingly popular these days due to evolution of internet of things. Monitoring and control of electronic, electrical and mechanical systems employed in different categories of buildings like commercial, industrial or residential can be done by using internet of things devices. Home automation and building automation systems, which provide automation services such as security monitoring, heating control and automatic lighting control, are required to link numerous terminals such as electromotor, cameras, sensors, lights etc. Thus, in-home power line communication technology appears to be an appropriate solution for operating networks with numerous apparatus at the terminals, especially inside very old residential and non-residential buildings having insufficient internal communication infrastructure [3].

A base station for controlling a power line communication network in the house and which is also likely to connect to the outdoor area may be placed at the meter unit or at another appropriate location in the PLC network of the house as shown in Fig.2 [6]. Each device of an in-home communication network is connected through power line communication modems, just like the subscribers of a power line communication access network [3]. Direct connection between the modems and wall sockets available all over the building is established. So, wherever power supply outlets are available, the in-home PLC network can be connected to various communication devices.

The PLC network in the home may exist as an independent network that includes a house or a building only. Although, controlling and using in-house PLC services remotely is an exception. However, in-house power line communication system which can be controlled remotely, is extremely comfy for the actualization of several automation functions, like energy management, security etc. In addition, the connection of another communication system to the in-house power line communication network permits the use of several telecommunications services from all the power outlets within the building [3].

Power line communication networks internal to a house can be linked to a power line access system as well as to an access network actualized by some other communication technology. If we do assessment of the first case considering that the access network is owned and maintained by an electricity company, extended metering services may be carried out; for example, remote reading of an electricity meter economize the capital investment on energy management and manual reading, which can be merged with a lucrative tariff system. At the same time, an in-house power line communication network can also be linked to the access networks offered by various network operators. So, the in-house network users can gain financially from the less restricted telecommunication market. In this way, a home power line communication network may also be utilised for control and monitoring of the connected systems using various communication technologies [3].

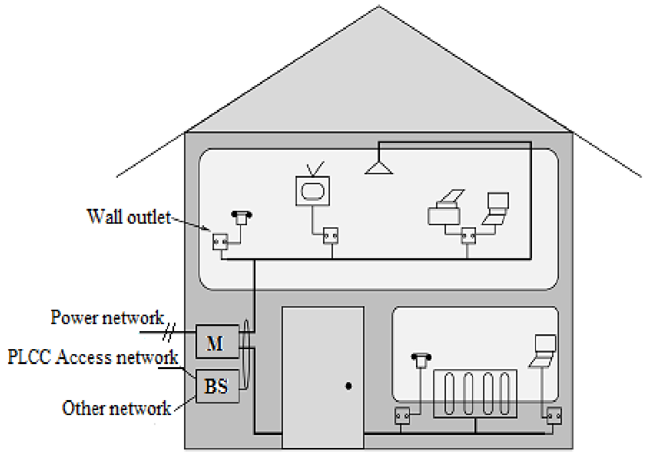

Fig.2. Home-building automation

III. TWO-WIRE TRANSMISSION LINE ANALYISIS

Whenever the lines supplying electrical power are used to broadcast radio frequency signals, they may be considered as transmission lines that direct the transverse electromagnetic waves through them. The electromagnetic field theory suggest that the two-wire transmission line should be a set of parallel conductors having fixed space between them [7]. In the real network of power cables, the conductors are just routed through the pipes and the spacing between them is not at all uniform. Although the pipes usually have a very small area of cross-section which restricts the inequality in separation of the cables. Therefore, the hypothesis of fixed distance is admissible in this case. On basis of the above assumption, the set of power conductors is considered as a distributed parameter network in which the currents and voltages can differ in phase and magnitude along its length. Thus, it may be explained by circuit parameters that are distributed over its length Δx as shown in Fig.3 [8].

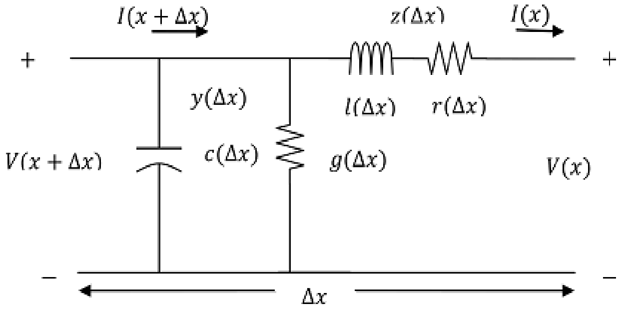

Fig.3. Two-wire transmission line equivalent circuit

The variables $v(x)$ and $v(x+\Delta x)$ represent the respective instantaneous values of voltages at points x and $x+\Delta x$. Likewise, $I(x)$ and $I(x+\Delta x)$ represent the respective instantaneous values of currents at points x and $x+\Delta x$. '*R'* is the resistance per unit length for both conductors (in Ω / m), '*L'* is the inductance per unit length for both conductors (in H/m), *G* is the conductance per unit length (in S/m), and *C* is the capacitance per unit length (F/m). Based on the lumped element circuit of a two wire transmission line as shown in the above figure, the equations for per unit length values of transmission line parameters at radio frequencies of MHz range, when distance 'D' between conductors is comparable to the radius 'a' of the conductor are given from (1) to (4) below:

Resistance 'R' = $1/\pi a\delta\sigma_c$ ………………….. (1)

Where 'δ'= skin depth $\sqrt{1/\pi f\mu_c\sigma_c}$. The skin depth is a function frequency '*f*' of the current in the conductor . Due to skin effect, the resistance of the conductor increases with increase in frequency of the current flowing in the conductor. The equations for line parameters are:

Inductance $$L=\frac{\mu_c}{\pi}a\cosh(D/2a)\ \text{………(2)}$$

Conductance $$G=\frac{\pi\sigma_d}{a\cosh(D/2a)}\ \text{………..(3)}$$

Capacitance $$C=\frac{\pi\varepsilon_d}{a\cosh(D/2a)}\ \text{………. (4)}$$

Here, μ_c = copper conductor permeability

σ_d = dielectric material conductivity, and

ε_d = dielectric material permittivity.

IV. Power Line Modelling

The modeling of a power line communication channel is based on a two-wire transmission line. The "hot" and "return" wires of the cable are used as power line communication channel. The wires of the cable are PVC insulated stranded copper conductors. Generally, in Indian houses, the cables are placed inside conduits of PVC in the walls. Although, the home-building power cable is approximated as a two-wire transmission line having non-stranded solid conductor to generalize and facilitate execution as shown in Fig.4 [6] below:

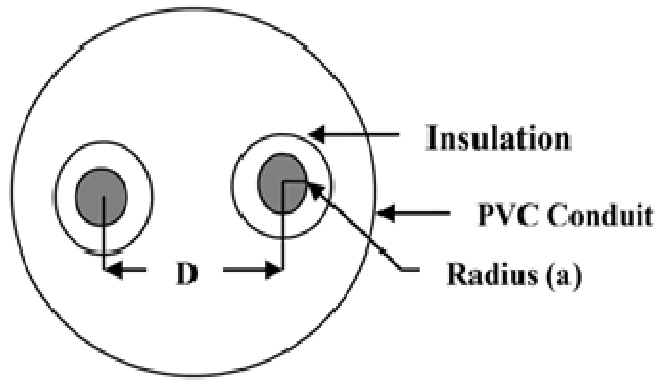

Fig.4: Approximate model of indoor power line

The insulating medium separating the wires is not uniform in contents (blend of air-insulating medium) as well as in separation (because of the circular shape of the conductor). As the cables are very near to each other, the insulation thickness 't' can be compared with that of the free space between the wires. In order to keep the model controllable, the dielectric is believed to be a stuff made up of different materials and the influence of non-uniform spacing between the conductors is not taken into account [9].

The spacing between live and neutral conductor is given by D = 2t + 2t + 2a, where 'a' is the radius of the conductor and t = insulation thickness = 0.7 mm. The conductor chosen is of copper having radius = 0.63 mm, which will give the spacing D = 4.06 mm between the conductors. The Table-1 below gives the electrical properties of the cable:

TABLE-I. Electrical Properties Of Cable

Copper conductivity	σ_c	$5.8\text{x}10^{7}$ S/m
Dielectric relative permittivity (PVC = 4 & AIR=1)	ε_r	0.8
Permeability of air	μ_g	$1.2\text{x}10^{-6}$(H/m)
Dielectric conductivity	σ_d	$1.0\text{x}10^{-5}$ S/m
Copper relative permeability	μ_r	1
Air permittivity	ε_g	$8.5\text{x}10^{-12}$(F/m)

The distributed variables of a transmission line are classified into primary and secondary parameters. The given formula [10] is used for approximation of these parameters whose values depend upon the specifications of the conductor.

The recent developments in energy storage systems [11] and photovoltaic technologies [12-13] in the field of non-conventional energy are playing an important role in reducing interferences in power line communication.

V. Transfer Function

The primary reasons for reduction in signal strength in power line communication are high temperatures, high radiations, longer line length, reflections due to impedance discontinuity points on the channel of propagation which causes damaging interference. The attenuation is also because of the main incident forward wave going out of phase with forward propagating wave. The frequency domain modeling strategy making use of scattering matrix method explains all these reflected and delayed paths in the interconnected power lines. ***S***-parameter matrix provides a relationship between incident **'*a*'** and reflected **'*b'*** power waves as detailed below for a two-port network [4].

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Here, $\boldsymbol{S_{21}}$ gives the Network Transfer Function.

MATLAB software is used as a simulation tool for determining the transfer function whose amplitude (dB) versus frequency plot provides the reduction in the signal magnitude and the plot between phase angle (radian) and frequency gives the distortion in phase or delay as shown in Fig.5 and Fig.6 respectively. At certain frequencies, the transmission of data is affected by the occurrence of heavy notches in the transfer function as shown in Fig.5. Therefore, such specifications of the cable are not chosen that create deep notch which delay and distort the signal. Hence, to establish data transmission between two access points, the chosen carrier frequency should not lie at the points of deep notches. Fig.7 shows the effect of increased line length on the modeled power line channel transfer function.

It is very much clear from Fig.6 that at certain frequency, whenever there is a deep notch in the transfer function, there is a delay or phase distortion due to the lack of continuity in the phase characteristics. The effect of increase in line length on phase spectrum of the modeled power line channel is shown in Fig.8.

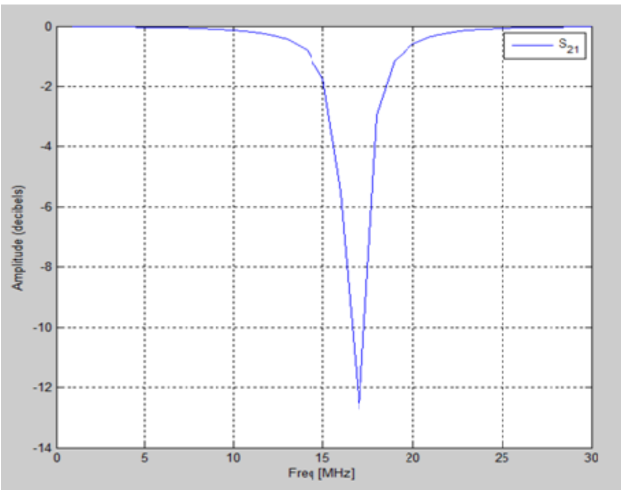

Fig.5: Amplitude spectrum of transfer function

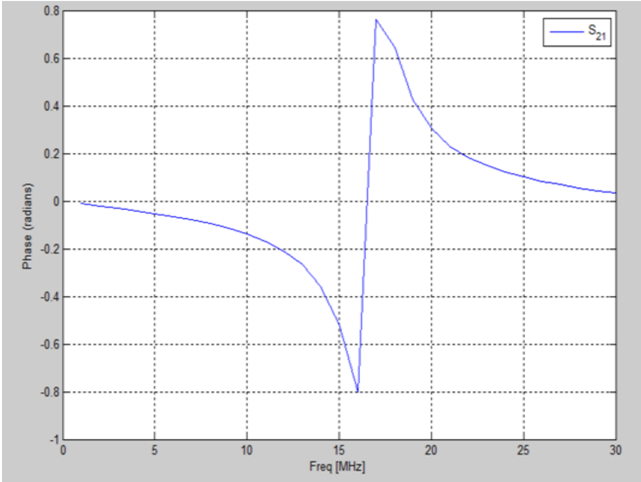

Fig.6: Phase spectrum of transfer function

We took the same set of frequencies, diameter and separation between conductors. Then we simulated the variations in channel length in MATLAB using RF tool. In this simulation the cable length was increased by 5 meters i.e. from l = 6 m to l = 11 m. The simulation results shown in the figure clearly indicate that the attenuation increases with increase in length [4].

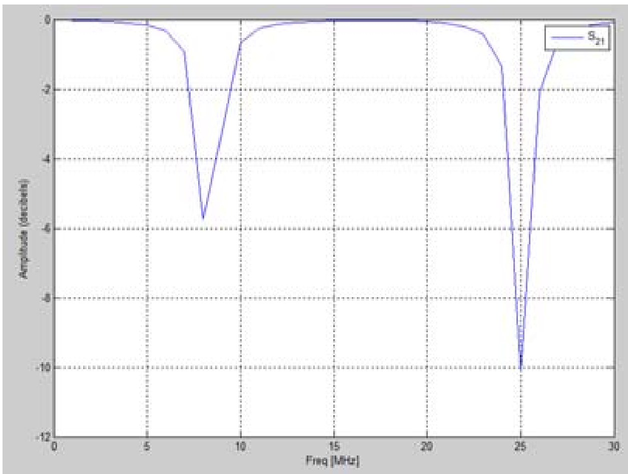

Fig.7: Amplitude spectrum of the transfer function when the length is increased

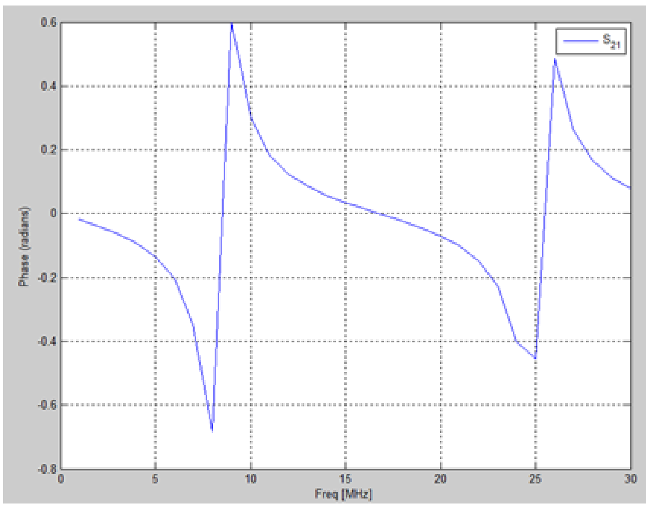

Fig.8: Phase spectrum of the transfer function when the length is increased

VI. Conclusion

Power line communication technology uses existing infrastructure of home-building. So, power line communication technology is considered as the cheapest available technology for home-building automation. However, some unwanted signals appear in the network which distort and delay the communication. This distortion and delay depend upon the primary and secondary parameters of the cable which are discussed in this paper and other factor also affect the communication like number of branches, line length and load. Therefore, a home-building indoor power line is modeled, and a software simulator is used to simulate the transfer function of the modeled power line. The simulation shows deep notch that affect the communication. When the length of the line is increased, keeping the other parameters exactly same as modeled power line, the simulation shows more distortion and delay. So, based on the simulation result, it may be concluded that if the line length is increased, the delay and the distortion in the spectrum of the modeled power line transfer function will also increase.

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