INVESTIGATING METHODS TO SIMULATE AND EVALUATE SIGNAL DISTRIBUTION IN ANALOG AND DIGITAL TV CABLE NETWORKS

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Abstract: The paper contains a theoretical and experimental study of transmission in analog and digital TV cable networks. The first part presents an overview of the most important concepts used in modeling of the most important components from cable network, and establish the models used in this specific research. The study is proposing in the first part to simulate, using Matlab models a TV cable network. This model is compared with different approaches, like electrical model simulation using Microcap environment. Finally, in experimental results section, the results of simulations are presented and compared with the evaluations realized by previous methods of simulation. The final goal of the research will be to validate, through cross-checking, the models written in Matlab (for theoretical study of DVB-C propagation in local -home – network) or practical purposes (CATV based data network design).
Keywords: *CATV network, Matlab simulation, Microcap , Headend*

I. INTRODUCTION

The TV cable systems were initially developed to carry the whole (or a part) of spectrum of analog television signals from a central point (headend) to the television receivers in each subscriber`s home. These systems were based on off-the-air antennas receiving the air signals from broadcast TV and were using other types of transmission lines although coaxial cables soon dominated. The frequency bandwidth of the cable system began to expand continuously once the satellite delivery of signals to cable systems was innovated, so the number of available TV channels increased as well.

In late 1990's the two-way cable TV systems were innovated and were able to support public demand for broadband telecommunication services. There are still differences between the American and European systems but some guidelines and technical basics are applicable for both.

These systems use the frequencies between 4 MHz and 42 MHz for upstream (from receiver to provider) transmission and the frequencies above 50 MHz for downstream (from provider to receiver) transmission. The 50-500MHz frequency bandwidth is used for carrying broadcast analog video, while the upper-frequency band (550MHz) is used for the digital services emerging. Besides the two-way communication between the customer and the headend, these new systems provide also video and non-video services and utilize the digital transmission.

Although the conversion to two-way communication allowed the best use of the increased program capacity by offering an easy means to purchase individual events using upgraded set-top boxes with upstream data transmitters included, it was faulty in large all coaxial networks systems due to the noise accumulated in upstream direction. In this sense the optoelectronic technology development was definitely a solution. By replacing trunk parts of the cable network with optical fiber and only keeping the last mile coax plants for distribution brings, a considerable increase in cable network's performances. These systems are called hybrid fiber/coax (HFC).

A classical cable system (Figure 1) has mainly five parts: the headend, the trunk cable, the distribution (feeder) cable in the neighborhood, the drop cable to the home and in-house wiring and the terminal equipment (subscriber's television set). The headend of a cable TV system represents the originating point of all the signals received from off-the-air antennas, parabolic satellite antennas or local sources via coaxial links or microwave links. The trunk system has the role of maintaining a good quality of the carried signal over long distances while delivering signals to customers through distribution system. Branching out of the trunk system, the distribution system has the role of delivering the signal to subscribers with an adequate signal level, while the drop cable is used to make the connection between the tap device and the subscriber home. The taps are used to connect distribution cables to drop cables, a typical tap containing a power splitter and a RF directional coupler.

II. THE CATV NETWORK MODEL

A complete CATV network is difficult to be simulated, because contains both optical and electrical components. Therefore, in this work we are analyzing only the final segment of the CATV network, the in-house distribution system, usually called drop-out segment.

In an in-house wiring configuration, from a central location near the TV signal source (a cable TV or a satellite dish) coaxial cables are connected to every room having a TV wiring connection available. This constitutes a typical star topology, where a multiport splitter is placed

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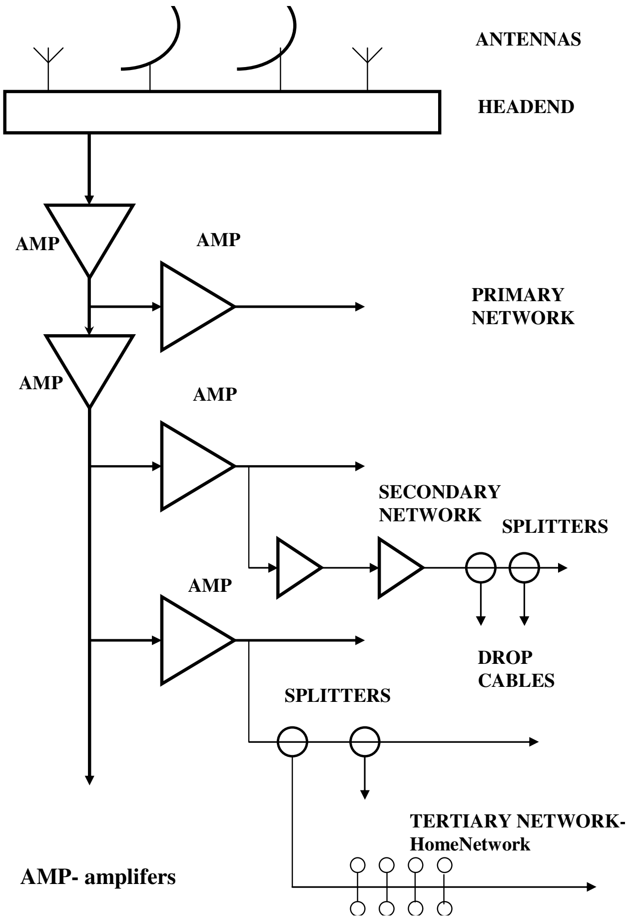

Figure 1. CATV cable topology and hierarchy [1][4]

at the center of the star. Depending on the number of rooms to be served, in some cases an amplifier is necessary between the video source and the multiport splitter in order to increase the level of the signal, compensating signal losses caused by branch splitting. For a signal separation loss of 15 dB between two output ports of every splitter stage, the minimal signal separation loss between coaxial cable outlets will be 15 dB. In general, splitters are randomly installed (for in-house wiring installed by TV cable companies on the existing homes) at the entrance point of the cable TV and some other convenient splitting points. This configuration forms a topology similar to that of the in-house telephone wiring (a star daisy-chain topology) except that at every branch point, a splitter is used. The same rule for maximum signal separation loss as for the star topology applies as well to the general star daisy-chain topology.

III. MODELS FOR COAXIAL TV NETWORK COMPONENTS

In this section, we will describe briefly the fundamentals of MATLAB and Microcap models together with the method and the parameters used to generate insertion loss and impulse response for a coaxial cable, by using its ABCD parameters. The primary parameters of coaxial cables have not been published yet by all producers, so in order to calculate the insertion loss and impulse response, we used estimated values of these parameters resulted

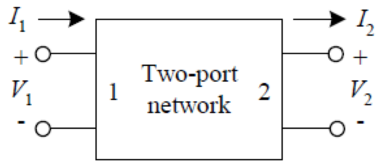

Figure 2. Two-Port Network

from laboratory experiments based on cable loss measurements as well as their physical dimensions and published in [2].

The coaxial cable, as a data carrier, was intensively investigated more than two decades ago [3], but with the replacement of coaxial Ethernet by twisted pair connections, this problem remained a matter for TV professionals. As an additional observation, TV technology is interested by the high frequency behavior of the cable, as TV signals (analog and digital) are carried by RF modulation.

The most common types of coaxial cables used in home wiring (drop cables) are RG-6 and RG-59. Based on different experiments and measurements, the attenuations for a 30 m coaxial cable have proven to be less than 10 dB at frequencies below 750 MHz. In order to provide an accurate representation of the transfer function of an in-house coaxial cable wiring used in calculus the ABCD parameters of a two-port network. The model of a two-port network is presented in figure 2 where I_1 and V_1 are the input voltage and current respectively, and I_2, V_2 are the voltage and current corresponding to the output port. These voltages and currents are related by the ABCD parameters, which usually are complex variables depending on frequency.

For a stand-alone two-port network, the following relationship can be used to calculate the currents and the voltages:

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \cdot \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \tag{1}$$

meaning $V_1 = AV_2 + BI_2$ and $I_1 = CV_2 + DI_2$.
The ABCD parameters are defined as:

$$A = \frac{V_1}{V_2}|_{I_2=0} \quad B = \frac{V_1}{I_2}|_{V_2=0}$$
$$C = \frac{I_1}{V_2}|_{I_2=0} \quad D = \frac{I_1}{I_2}|_{V_2=0} \tag{2}$$

If we consider a series impedance (Z) the parameters are:

$$A = \frac{V_1}{V_2}|_{I_2=0} = 1, \quad B = \frac{V_1}{I_2}|_{V_2=0} = Z,$$
$$C = \frac{I_1}{V_2}|_{I_2=0} = 0, \; D = \frac{I_1}{I_2}|_{V_2=0} = 1 \tag{3}$$

For a parallel impedance (Z) the corresponding equations are:

$$A = \frac{V_1}{V_2}|_{I_2=0} = 1, \quad B = \frac{V_1}{I_2}|_{V_2=0} = 0,$$

$$C = \frac{I_1}{V_2}|_{I_2=0} = \frac{1}{Z},\ D = \frac{I_1}{I_2}|_{V_2=0} = 1 \quad (4)$$

Based on equations (3) and (4), the ABCD matrix corresponding to a two-port network with serial impedance (5), respectively with a parallel impedance (6) are the following:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Z^{-1} & 1 \end{bmatrix} \quad (6)$$

This general set of equations can be developed for each component involved in cable network model. The basic set of components implemented used in this work is composed from splitters and the carrier (coaxial cable). The challenges are even higher in two-way and interactive TV networks as described in [5].

A. Splitter model

Splitters are user at coaxial cable branch point where it's required an impedance match as well as an even distribution of powers. In a TV connection with at least two TV sets splitters with two or more output ports are necessary. The structure of a splitter with an input port and two output ports is given in the figure 3, where the primary coil has an intermediate tap and is used for impedance matching but generates also an

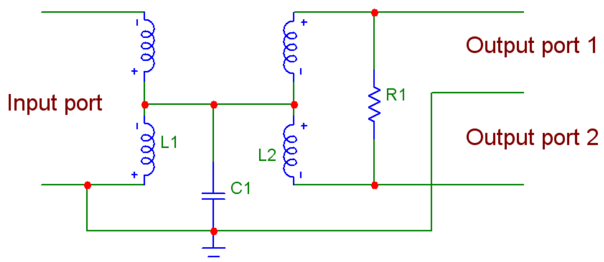

Figure 3. The structure of a splitter with one input port and two output ports

electromagnetic field for transferring the energy to the second coil.

The impedances belonging to each half of the second coil appear in parallel with the first coil, the resistor across the two ends of the second coil being used to introduce an out-of-phase signal in order to reduce the magnetic coupling between the output ports. The role of the capacitor is to fine-tune the splitter's frequency response across the wide range of the frequency band. The layout components of a splitter can also influence its frequency response when operating at very high frequencies.

B. Coaxial cable (channel) model

In channel's model implementation we'll make use again of the ABCD parameters, so in order to ease up the computations for a larger range of parameters and to simplify the corresponding MATLAB code, we created first a MATLAB file containing values of the RLGC parameters (resistance, inductance, conductance and capacitance). Based on these parameters, are computed later on the ABCD parameters, considering that the type of coaxial cable used is RG-6. The attenuations on such a cable is given by the formula:

$$A_T = (K_1\sqrt{f} + K_2 f)d \quad (7)$$

where f is the frequency, d is the cable's length and K_1 is a constant parameter indicating the amount of conductor loss, while K_2, also a constant parameter, indicates the amount of dielectric loss. For RG-6 coaxial cable type, the values of these parameters, recommended in reference [2], are: $K_1 = 2.1144$ and $K_2 = 0.002$. The attenuation can also be related to the serial resistance *R(f)*, so we can rewrite (7) as follows:

$$A_T = (K_1\sqrt{f} + K_2 f)d = -20\log e^{-\frac{R(f)d}{2Z_0}} \quad (8)$$

IV. EXPERIMENTAL RESULTS

Network Models

A major problem in signal flow simulation of cable broadcasting networks, is that, although generally accepted models and mathematical device are pretty well established, the results differ significantly from implementation to implementation. Dependency is quite marked, especially if simulation tools used are from different categories: pure math - Matlab, or based on circuit simulation - Microcap, Spice or similar.

Our research is focused on highlighting these differences, if any, and the evaluation of errors generated by using either of the two categories. It is obvious that engineers prefer to use circuit simulation models, generally based on Spice compatible environments. General mathematical simulation, Matlab type, proposed in [2] as a basic investigation technique, but difficult to be used for the engineering community, in day by day applications (practical design, analysis).

For this purpose we tried to implement several scenarios, designed, in our opinion, to clarify these cases. Shortly, these steps for each scenario are:

1. Generating models of similar components using Matlab, respectively Microcap;

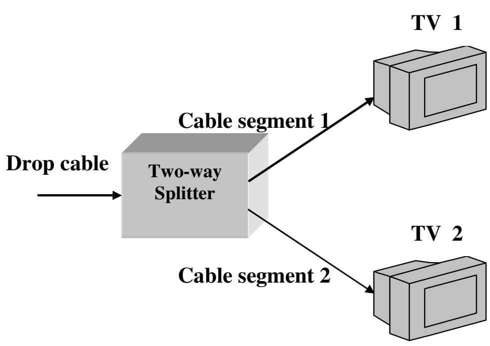

Figure 4. A simple home cable network with a splitter

2. Implementing the same network (circuit) using both methods;
3. Evaluation of the main parameters of interest in each model;
4. Evaluating the differences.

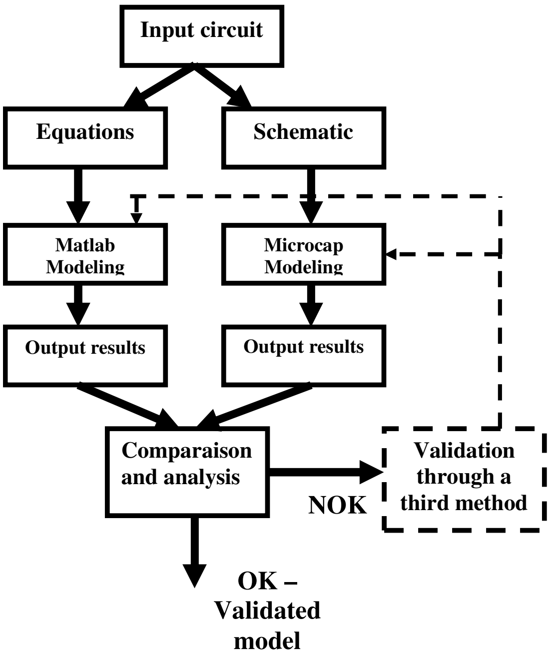

Figure 5. Proposed model validation procedure

Briefly, this procedure is described in figure 5. The dashed components are not implemented yet, since possible candidates for a third method, better than the two previously described (Matlab and Microcap), are under investigation.
Of course, the final goal should be practical measurements for each configuration, based on well defined test-beds, approaches described in [2] [6] or [7]. The cost of the practical implementation and the necessary equipment is unjustifiably high against the benefits they would bring. In this stage of the research this approach is not explored yet.

In the following sections we are presenting few preliminary results, in this research.

For network simulation we have chosen Microcap circuit analysis environment. It is well known in electrical engineering and electronics to be very efficient and includes accurate models.

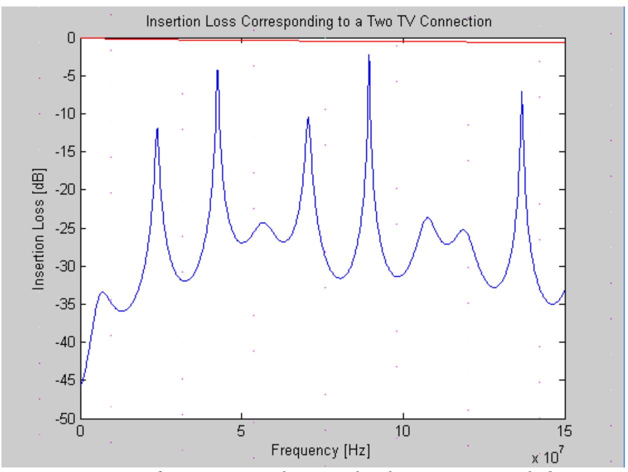

Figure 6. Insertion loss calculation in Matlab

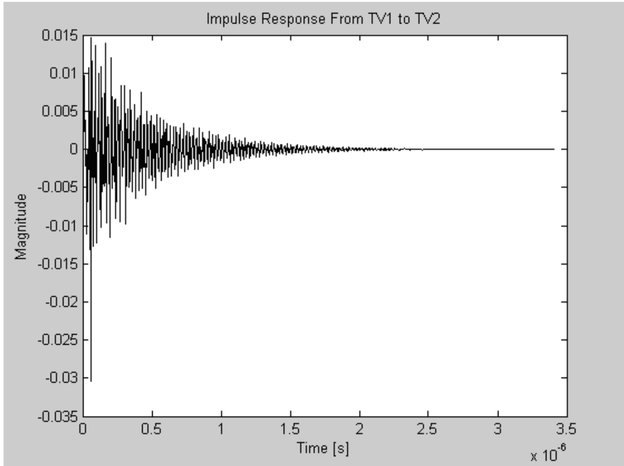

Figure 7. Impulse response in Matlab simulation

To check the feasibility of this research, we chose a simple circuit consisting of a two-way splitter and two coaxial lines, as shown in Figure 4.

Matlab model implementation

This paragraph contains the corresponding MATLAB based calculation for loss and impulse response of the structure of an in-house coaxial cable wiring with two TV sets as presented in figure 4. For this structure, one switch having an input port and two output ports is necessary to ensure the connection of the two TV sets, the transmission path between the two TV connection points covering the output port-to-output port connection of the splitter. Since the coaxial cable is relatively short and the frequency is not very high for the available gap between the reverse channel from TV 1 to splitter and the second TV channel (from splitter to TV 2, most of the signal attenuation is produced by the output port-to-output port connection of the splitter.

For the considered structure, we can calculate the insertion loss and the impulse response corresponding to the path from TV1 to TV2, by using ABCD parameters. As can be seen in figure 4, this transmission path, covers two sections of coaxial cable and one output port-to-output port connection of a splitter. A proper result can be obtained by cascading the ABCD matrix corresponding to the first section of coaxial cable (from TV1 to splitter) with the ABCD matrix of the output port-to-output port path of the splitter, then cascading the resulted matrix with the one of the second section of coaxial cable (from splitter to TV2). We will consider different lengths for the two sections of cable, for example in the presented diagrams the length of the first section of 25 m, and the length of the second one 35m.

The results presenting the insertion loss (vs. frequency) of the model implemented in Matlab based on [2], for the structure with 2 TV sets, are presented in figure 6 (in blue). In the same diagram (red line – visible in upper part of diagram) is presented the insertion loss for a simple coaxial cable. It is obvious that the splitter is altering significantly the amplitude characteristics of the whole system.

The impulse response corresponding to the in house wiring structures are presented in figure 7. The figures represent the magnitude of the signal over the time domain in order to see how fast the signal attenuates across the considered wiring structures. In order to interpret these results we have to consider that in coaxial cables, like in any other transmission lines some reflection of the transmitted signal may appear. This evaluation is important in scenarios with complex (mixed) distribution (eg. data and TV signals) to evaluate the influence of one equipment against the second, in disturbance propagation.

Microcap models implementation

Microcap models are implemented somehow easier, because the environment is adapted to the analysis of electrical and electronic circuits in an intuitive, engineering approach. The actual configuration of predefined models from Microcap is not so simple, since the parameters must be defined and written carefully for each type of coaxial cable. Reference [9] gives an idea about the difficulties of this approach. Since the results for Microcap simulation are in an early stage, we will present the simplest models implemented.

Figure 7 presents the schematic for a simple splitter with two outputs.

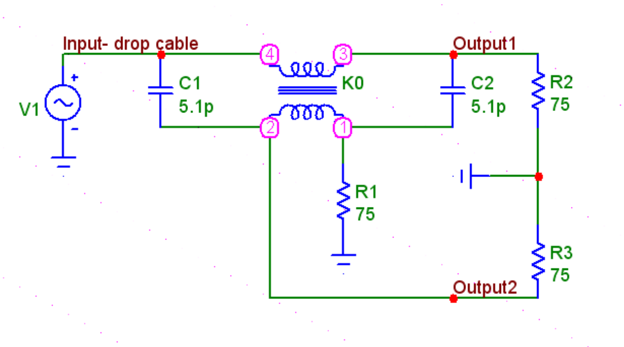

Figure 8. Microcap model of a simple splitter

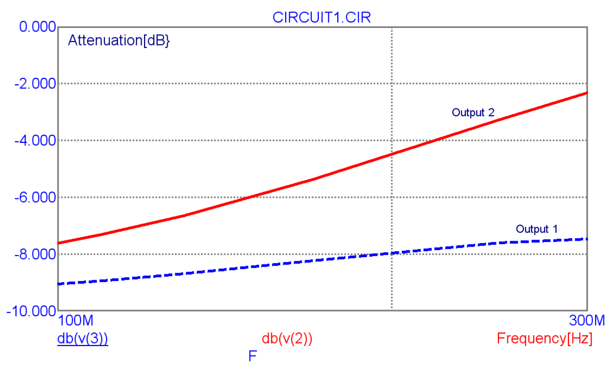

Figure 9. AC characteristic for the outputs of the simple splitter (k=0.99)

Investigating the output characteristics of this simple circuit, it is possible to observe, that for a coupling factor (k) of the transformer of 0.99, the AC output characteristics are significantly different, as presented in figure 9. It is possible to observe that this simple circuit has a non-balanced behavior in VHF (100-300MHz) domain. For k=0.95 (figure 10) the output characteristics are totally divergent, altering also the behavior of the connected equipment (TVs or Cable Modems).

V. CONCLUSIONS

In this paper we have investigated few models and two different categories of tools, able to implement and validate a coherent model of the drop-out and in-house connections of cable TV network.

Starting from classical models of the major components for the cable network, we tried to investigate the influence of several parameters and the environment chosen for implementation.

This series of experiments has multiple theoretical and practical conclusions. It is possible to see that the results are influenced not only by the model chosen for implementation, but there are strong influences of the simulation system. Math precision and low level components modeling, included in the environment are causing minor and, in some cases, major differences in the final results.

In conclusion, these models are useful in finding the wiring configuration within the house which provides us the best transmission capabilities. The presented scenarios are established for a specific configuration and for a single type of coaxial cable, so for other wiring structures

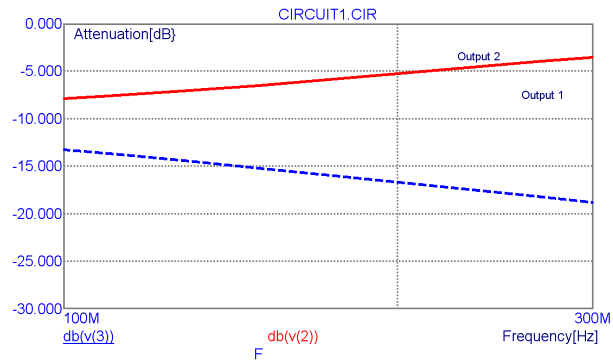

Figure 10. AC characteristic for the outputs of the simple splitter (k=0.95)

([8]) or other types of coaxial cables, they cannot be used directly. This is particularly true for Matlab implementation. However, it's relatively easy to adapt them to other situations since it's enough to replace the parameters of the cable, the numbers of splitters and other values of the model. A feasible solution would be to create a dedicated library with components for different cables, and components (splitters, taps, hubs).

The future research will try to integrate two-way cable TV networks, so called Interactive Television Cable Network – ICATV. extending the possibilities to evaluate not only the one-way distribution (TV only) but data communication via cable TV using DOCSIS standards [10].

The same research could be useful for advanced approaches of data and TV signals distribution in future homes, proposed by new standards like MoCA. The network described in [11] will be reanalyzed using the principles presented in this paper, in terms of transmission capacity.

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REFERENCES

[1] Walter S. Ciciora. *Modern Cable Television Technology: Video, Voice and Data Communications*, Morgan Kaufman, 2004
[2] Walter Y. Chen, *Home Networking Basis: Transmission Environments and Wired/Wireless Protocols*, Prentice Hall, 2003
[3] Chu Sun Yen, Richard D. Crawford, "Distribution and Equalization of Signal on Coaxial Cables used in 10Mbit/s Baseband Local Area Networks", *IEEE Transactions on Communications,* Vol Com-31, No 10, October 1983, pp. 1181-1186
[4] J. Hlubík, L. Schwartz, V. Hottmar, "CATV Network Evolution", *Advances in Electrical and Electronic Engineering*, Vol 5, No 1 - 2 (2006), pp.27-30
[5] Hernan Galperin, François Bar, "Open Access beyond cable: The case of Interactive TV", 29th Telecommunication Policy Research Conference 2001, *Communication & Strategies 46(2)*: pp.75-98
[6] Harald Gsödl; Peter Lampel, "Realistic simulation: cable TV networks for J.83/B and DOCSIS 3.0", *Rohde-Schwartz News* 201/2010
[7] W.Y Chen,K Kerpez, "Coaxial cable distribution plant performance simulation for interactive multimedia TV", Proceedings of *IEEE Global Telecommunications Conference, 1995. GLOBECOM '95*, pp.173 – 177
[8] Anders Lehmann, Klaus Kolle, "Simulation of channel characteristics for complex networks", *Proceedings of Third Workshop of Power Line Communications*, October 2009, Udine
[9] S. Caniggia,. F. Maradei, "Equivalent circuit models for the analysis of coaxial cables immunity", *Proceedings of 2003 IEEE International Symposium on Electromagnetic Compatibility,* vol.2 , 2003, pp. 881 - 886
[10] C. Smythe, P.Tzerefos, V.Sdralia, V.Rangel, G.Manson and S. Cvetkovic, "Cable Modems and The Return Channel Path For Interactive Services: DOCSIS vs. DVB – A Performance Evaluation", *Proceedings of IBC Television Distribution Technology 99*
[11] Radu Arsinte, Eugen Lupu, Simina Emerich, "A Generic Platform to Study the Basic Aspects of DVB-IPTV Conversion Process", - *Proceedings of International Symposium on Signals, Circuits and Systems- ISSCS 2011*, Iasi, Romania , June 30 - July 1, 2011, pp.65-68