2.4 Generic Models of DSL Cables

In addition to huge databases of measurements that have been made available through co-operative studies encouraged by standardization bodies, models of cables have been derived in order to accurately describe the behavior of the primary parameters. Utilizing these models avoids referencing large tables of measurements when computing the two-port characteristics of any DSL line. Although physical principles have inspired the models, many are rather empirical. Ease of use and compactness have been the principal requirements. This section follows part of the presentation in [Van den Brink 1998]. The report introduces the principle of measuring large sections of homogeneous cables (rather than short ones as recommended previously) and performing the full two-port extraction of the four primary parameters on these long sections. This approach resulted in an improvement in accuracy, as cable sections of several hundred meters can now be characterized as full two-port networks (magnitude and phase) with a phase accuracy corresponding to 1 cm of cable length uncertainty. Two classes of model parameters are proposed: (a) model parameters focusing on modelling the primary parameters, *RLCG*, and (b) model parameters focusing on the modelling of secondary parameters. The first class of models was proposed by British Telecom [Cook 1996] [Lawrence 1996] and KPN [Van den Brink 1997a] [Van den Brink 1997b] [Van den Brink 1998]. These models have proven to be especially useful to describe cable behavior over a range of frequencies from DC to tens of MHz with good precision. The second class of models was proposed by Swisscom [Pythoud 1998] and Deutche Telekom [Pollakowski 1996]. In this chapter, the presentation is restricted to the first class of model; for details on the second class of model, the interested reader is referred to the ETSI report [Van den Brink 1998].

2.4.1 The British Telecom Models 0 and 1 (*RLCG* Modelling)

Used all over the world now, these two empirical models were first proposed by John Cook of British Telecom [Cook 1996] [Lawrence 1996].

2.4.1.1 Empirical Model for Resistance

As frequency increases, the current flow in a wire becomes less uniform across the cross section and tends to concentrate close to the wire surface; this behavior is known as the skin effect. As the skin effect accounts for the current flow at high frequencies, the resistance of the wire increases drastically. It is well known that once the skin effect becomes dominant, it increases in proportion to $\sqrt{f}$. At a range of low frequencies below where the skin effect is dominant, the wire resistance is close to the DC resistance. This has suggested an empirical model of the form

$$R(f) = \sqrt[4]{\left(R_{oc}^4 + a_c f^2\right)}. \tag{2.97}$$

To further complicate matters, some types of aerial drop-wire are bimetallic, where a copper outer conductor is mechanically reinforced by a steel inner core. As steel is a material with a large relative permeability, the skin effect dominates more at lower frequencies than in the copper conductor. It has been found that a good empirical model can be obtained by extending the model Equation 2.97 to include a hypothetical separate conductor with the same model as above but different parameters, suggesting the overall model:

$$R(f) = \frac{1}{\frac{1}{\sqrt[4]{(R_{oc}^4 + a_c f^2)}} + \frac{1}{\sqrt[4]{(R_{os}^4 + a_s f^2)}}}, \tag{2.98}$$

where R_{oc} is the DC resistance due to copper and R_{os} is the DC resistance due to steel. The separate skin effects for copper and steel are accounted for by a_c and a_s.

2.4.1.2 Empirical Model for Inductance

At low frequencies where the skin effect is not dominant, the parameter L exhibits a constant inductance L_0. At high frequencies, when the skin effect is dominant, the L parameter tends toward a constant inductance L_∞. The inductance model has been empirically modelled through

$$L(f) = \frac{L_0 + L_\infty \left(\frac{f}{f_m}\right)^b}{1 + \left(\frac{f}{f_m}\right)^b}, \tag{2.99}$$

where b and f_m are parameters that control the transition between L_0 and L_∞ across the frequency axis.

2.4.1.3 Appropriate Model for Conductance

A suitable model for cable conductance has been found to be

$$G(f) = g_0\, f^{g_e}, \tag{2.100}$$

where g_0 and g_e control the behavior of an exponentially increasing dielectric loss.

2.4.1.4 Empirical Model for Capacitance

A suitable model for capacitance has been found to be

$$C(f) = C_\infty + C_0 f^{-c_e}. \tag{2.101}$$

For good dielectrics, C_0 can be considered to be negligible, and the capacitance model is C_∞. Poorer dielectrics such as PVC may need the complete model given by Equation 2.101.

TABLE 2.2

BT #0 Modelling Parameters for European Cables of Several Sections as Described by ETSI in the G.996.1 Recommendation

Cable Section	0.32 mm	0.40 mm	0.5 mm	0.63 mm	0.90 mm
r_{0c} (Ω/km)	409	280	179.2	113	55.1
a_c (Ω^4/km^4 Hz^2)	0.3822	0.0969	0.0561	0.0257	0.0094
L_0 (μH/km)	607	587.3	674.6	699.4	750.9
L_∞ (μH/km)	500	426	532.7	477.2	520.5
b	5.269	1.385	1.195	1.0956	0.9604
f_m (Hz)	609000	745900	664700	265800	123800
C_∞ (nF/km)	40	50	50	45	40
C_0 (nF/km)	0	0	0	0	0
c_e	1	1	1	1	1
g_0 (S/km)	0	0	0	0	0
g_e	1	1	1	1	1