

TTC DSL専門委員会 スペクトル管理SWG (第9回)

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題名：B章に関わる追加情報

(1) 背景

B章アドホック(2004/03/17開催)にて、JJ-100.01 B.3章 式(B.4)に与えられる線路の1次定数R, L, C, Gの計算値を例示することが提案されたので、紹介する。

(2) B.3章・式(B.4)の計算結果

表 1次定数の計算値(0.4mmCCPケーブル)

周波数	項目	計算値(1km当たり)
160kHz	$R [=2(R_i+R_n+R_{ns})]$	313.46[ohm/km]
	$2R_i$	286.26[ohm/km]
	$2R_n$	5.4394[ohm/km]
	$2R_{ns}$	21.757[ohm/km]
	$L [=2(L_a+L_i+L_n+L_{ns})]$	700.95×10^{-6} [H/km]
	$2L_a$	616.20×10^{-6} [H/km]
	$2L_i$	97.846×10^{-6} [H/km]
	$2L_n$	-2.6198×10^{-6} [H/km]
	$2L_{ns}$	-10.479×10^{-6} [H/km]
	C	50×10^{-9} [F/km]
	G	25.13×10^{-6} [mho/km]

(3) 過去の文献

ITU-T勧告G.996.1(G.test) 6.1.3節にR,L,C,Gの計算結果が既に例示されている(別紙参照)。

(4) まとめ

情報提供目的である。

別紙 ITU-T G.996.1 6.1.3 節の抜粋

6.1.3 Test loops in an environment coexisting with TCM-ISDN DSL

(中略)

Primary line constants

The primary line constants are R , L , C , and G . The variation of R , L , and G with frequency can be accurately calculated by the equations shown below. The coefficients for the calculation of R , L , and G are given in Table 11. The equations below give the value of R in ohm/m, L in H/m, G in mho/m, C in F/m, and f in Hz by using the coefficient values shown in the table. Note that the capacitance C is assumed constant with frequency ($C = 50$ pF/m). The primary line constants (R , L , G , and C) calculated by the equations below for the cable types referenced in Figure 11 are shown in Tables 13 to 17, as a function of frequency, where the values are indicated R in ohm/km, L in μ H/km, G in μ mho/km, C in nF/km, f in kHz, and at a temperature of 20° C.

$$R = 2(R_i + R_n + R_{ns}) \quad [\text{ohm/m}]$$

$$L = 2(L_a + L_i + L_n + L_{ns}) \quad [\text{H/m}]$$

$$G = \omega C \tan \delta \quad [\text{mho/m}]$$

$$C = 50 \times 10^{-12} \quad [\text{F/m}]$$

$$R_i = \frac{1}{\pi r^2 \sigma} f_i^{(R)} = \frac{1}{\pi r^2 \sigma} \operatorname{Re} \left[\frac{1+j}{2\delta} r \frac{J_0\left(\frac{1+j}{\delta} r\right)}{J_1\left(\frac{1+j}{\delta} r\right)} \right]$$

$$R_n = \frac{1}{\pi \sigma d^2} f_n^{(R)} = \frac{1}{\pi \sigma d^2} \operatorname{Re} \left[-\frac{1+j}{\delta} r \frac{J_1\left(\frac{1+j}{\delta} r\right)}{J_0\left(\frac{1+j}{\delta} r\right)} \right]$$

$$R_{ns} = \frac{1}{\pi \sigma d^2} 4 f_n^{(R)} = \frac{4}{\pi \sigma d^2} \operatorname{Re} \left[-\frac{1+j}{\delta} r \frac{J_1\left(\frac{1+j}{\delta} r\right)}{J_0\left(\frac{1+j}{\delta} r\right)} \right]$$

$$L_a = \frac{\mu_0}{2\pi} \ln\left(\frac{d}{r}\right)$$

$$L_i = \frac{\mu_r \mu_0}{2\pi} f_i^{(L)} = \frac{\mu}{2\pi} \operatorname{Re} \left[-\frac{\delta}{(1+j)r} \frac{J_0\left(\frac{1+j}{\delta} r\right)}{J_1\left(\frac{1+j}{\delta} r\right)} \right]$$

$$Ln = -\frac{\mu_0}{2\pi} \left(\frac{r}{d}\right)^2 f_n^{(L)} = -\frac{\mu_0}{2\pi} \left(\frac{r}{d}\right)^2 \operatorname{Re} \left[-\frac{J_2\left(\frac{1+j}{\delta} r\right)}{J_0\left(\frac{1+j}{\delta} r\right)} \right]$$

$$Lns = -\frac{\mu_0}{2\pi} \left(\frac{r}{d}\right)^2 4f_n^{(L)} = -\frac{\mu_0}{2\pi} \left(\frac{r}{d}\right)^2 4 \operatorname{Re} \left[-\frac{J_2\left(\frac{1+j}{\delta} r\right)}{J_0\left(\frac{1+j}{\delta} r\right)} \right]$$

where:

$\omega = 2\pi f$ angular frequency

r the radius of a conductor

σ conductivity of copper (conductor)

$$\delta = \sqrt{\frac{2}{\omega \sigma \mu_r \mu_0}} \quad \text{skin depth}$$

$d = 2\sqrt{2}(r + c_0)$ the distance between the conductor centres of a pair

c_0 the insulator thickness of a wire

μ_r relative permeability of copper (conductor)

μ_0 permeability of vacuum

Table 11/G.996.1 Coefficients for calculation of R and L

Coefficient	Paper				Polyethylene				
	0.4 mm	0.5 mm	0.65 mm	0.9 mm	0.32 mm	0.4 mm	0.5 mm	0.65 mm	0.9 mm
r (m)	0.2×10^{-3}	0.25×10^{-3}	0.325×10^{-3}	0.45×10^{-3}	0.16×10^{-3}	0.2×10^{-3}	0.25×10^{-3}	0.325×10^{-3}	0.45×10^{-3}
c_0 (m)	0.09×10^{-3}	0.11×10^{-3}	0.17×10^{-3}	0.24×10^{-3}	0.05×10^{-3}	0.13×10^{-3}	0.15×10^{-3}	0.20×10^{-3}	0.27×10^{-3}
μ_r	1								
μ_0 (H/m)	$4\pi \times 10^{-7}$								
σ (mho/m)	5.8×10^7								
$\tan \delta$	2.5×10^{-2}				4.0×10^{-4}	5.0×10^{-4}			

The variation of R and L with frequency can be accurately modelled as follows. The five coefficients for the cable types referenced in Figure 11 are given in Table 12. The approximate equations below give the values of R in ohm/m, L in H/m, G in mho/m, C in F/m, and f in Hz by using the coefficient values shown in the table.

Table 13/G.996.1 RLC values for 0.4 and 0.5 mm paper-insulated cables

Frequency (kHz)	0.4 mm C = 50 nF/km		0.5 mm C = 50nF/km	
	R (ohm/km)	L (μ H/km)	R (ohm/km)	L (μ H/km)
0.00	274.41	664.51	175.62	661.75
2.50	274.42	664.51	175.64	661.73
10.00	274.62	664.42	175.97	661.52
20.00	275.28	664.15	176.99	660.85
30.00	276.36	663.69	178.68	659.74
40.00	277.87	663.07	180.99	658.24
50.00	279.78	662.27	183.88	656.37
100.00	294.75	656.09	204.86	643.13
150.00	316.56	647.33	231.49	627.35
200.00	342.22	637.42	258.98	612.46
250.00	369.40	627.46	285.41	599.57
300.00	396.69	618.03	310.31	588.68
350.00	423.38	609.41	333.73	579.47
400.00	449.19	601.65	355.79	571.61
450.00	474.02	594.68	376.61	564.83
500.00	497.90	588.42	396.34	558.92
550.00	520.87	582.79	415.08	553.73
600.00	542.99	577.69	432.93	549.13
650.00	564.30	573.06	449.98	545.03
700.00	584.86	568.84	466.34	541.34
750.00	604.72	564.98	482.06	538.02
800.00	623.92	561.42	497.22	535.00
850.00	642.50	558.15	511.88	532.24
900.00	660.52	555.11	526.09	529.71
950.00	678.00	552.30	539.88	527.38
1000.00	694.99	549.69	553.30	525.23
1050.00	711.52	547.25	566.38	523.23
1100.00	727.62	544.96	579.14	521.37

Table 14/G.996.1 RLC values for 0.65 and 0.9 mm paper-insulated cables

Frequency (kHz)	0.65 mm C = 50nF/km		0.9 mm C = 50nF/km	
	R (ohm/km)	L (μ H/km)	R (ohm/km)	L (μ H/km)
0.00	103.92	684.18	54.20	686.87
2.50	103.95	684.15	54.27	686.73
10.00	104.45	683.60	55.20	684.79
20.00	106.02	681.89	57.98	679.07
30.00	108.52	679.19	62.04	670.97
40.00	111.83	675.66	66.81	661.83
50.00	115.78	671.51	71.88	652.64
100.00	140.25	647.61	96.11	616.45
150.00	165.42	626.69	116.50	594.37
200.00	188.55	610.67	133.77	579.83
250.00	209.58	598.33	148.81	569.58
300.00	228.77	588.57	162.27	561.93
350.00	246.38	580.67	174.61	555.98
400.00	262.68	574.16	186.08	551.17
450.00	277.89	568.69	196.86	547.19
500.00	292.19	564.04	207.06	543.81
550.00	305.73	560.02	216.77	540.90
600.00	318.64	556.51	226.06	538.36
650.00	331.01	553.41	234.97	536.11
700.00	342.90	550.65	243.55	534.10
750.00	354.37	548.17	251.83	532.30
800.00	365.47	545.92	259.84	530.67
850.00	376.23	543.88	267.60	529.18
900.00	386.68	542.00	275.14	527.82
950.00	396.85	540.27	282.47	526.57
1000.00	406.77	538.67	289.61	525.41
1050.00	416.44	537.19	296.58	524.33
1100.00	425.88	535.81	303.38	523.33

Table 15/G.996.1 RLC values for 0.32, 0.4 and 0.5 mm polyethylene-insulated cables

Frequency (kHz)	0.32 mm C = 50nF/km		0.4 mm C = 50nF/km		0.5 mm C = 50nF/km	
	R (ohm/km)	L (μH/km)	R (ohm/km)	L (μH/km)	R (ohm/km)	L (μH/km)
0.00	428.76	624.66	274.41	716.20	175.62	703.89
2.50	428.77	624.66	274.42	716.19	175.64	703.88
10.00	428.92	624.62	274.59	716.13	175.91	703.70
20.00	429.41	624.48	275.12	715.91	176.79	703.14
30.00	430.23	624.26	276.02	715.55	178.23	702.23
40.00	431.37	623.94	277.25	715.05	180.20	700.98
50.00	432.83	623.54	278.83	714.42	182.66	699.43
100.00	444.67	620.31	291.19	709.50	200.68	688.42
150.00	463.20	615.30	309.35	702.50	223.85	675.19
200.00	486.98	608.97	330.92	694.53	248.16	662.55
250.00	514.44	601.81	354.05	686.44	271.91	651.46
300.00	544.17	594.24	377.58	678.73	294.59	641.96
350.00	575.05	586.61	400.91	671.59	316.14	633.82
400.00	606.26	579.16	423.72	665.08	336.56	626.79
450.00	637.24	572.03	445.91	659.18	355.93	620.66
500.00	667.67	565.31	467.42	653.82	374.32	615.28
550.00	697.37	559.03	488.25	648.94	391.79	610.53
600.00	726.25	553.18	508.41	644.49	408.45	606.30
650.00	754.29	547.75	527.90	640.42	424.36	602.52
700.00	781.52	542.72	546.76	636.68	439.60	599.12
750.00	807.95	538.05	565.01	633.23	454.24	596.04
800.00	833.64	533.70	582.67	630.05	468.35	593.25
850.00	858.61	529.65	599.77	627.10	481.98	590.69
900.00	882.92	525.88	616.36	624.36	495.18	588.35
950.00	906.60	522.34	632.44	621.82	508.00	586.20
1000.00	929.68	519.03	648.07	619.45	520.46	584.20
1050.00	952.21	515.92	663.27	617.23	532.60	582.35
1100.00	974.20	513.00	678.07	615.15	544.44	580.62

Table 16/G.996.1 RLC values for 0.65 mm and 0.9 mm polyethylene-insulated cables

Frequency (kHz)	0.65 mm C = 50nF/km		0.9 mm C = 50nF/km	
	R (ohm/km)	L (μ H/km)	R (ohm/km)	L (μ H/km)
0.00	103.92	707.72	54.20	703.89
2.50	103.95	707.69	54.26	703.77
10.00	104.41	707.19	55.14	701.96
20.00	105.84	705.66	57.75	696.66
30.00	108.14	703.22	61.57	689.13
40.00	111.17	700.03	66.08	680.63
50.00	114.81	696.28	70.89	672.04
100.00	137.50	674.59	94.16	637.90
150.00	161.20	655.37	113.97	616.72
200.00	183.24	640.46	130.78	602.67
250.00	203.43	628.83	145.41	592.72
300.00	221.91	619.57	158.49	585.30
350.00	238.88	612.03	170.48	579.52
400.00	254.58	605.79	181.62	574.85
450.00	269.22	600.55	192.09	570.98
500.00	282.98	596.08	202.00	567.70
550.00	296.00	592.23	211.44	564.88
600.00	308.41	588.86	220.46	562.41
650.00	320.29	585.88	229.12	560.22
700.00	331.71	583.23	237.45	558.28
750.00	342.73	580.85	245.50	556.53
800.00	353.40	578.69	253.28	554.94
850.00	363.73	576.73	260.82	553.50
900.00	373.78	574.93	268.14	552.18
950.00	383.55	573.27	275.27	550.96
1000.00	393.07	571.73	282.20	549.83
1050.00	402.36	570.31	288.97	548.79
1100.00	411.44	568.98	295.58	547.81

Table 17/G.996.1 G values

Frequency (kHz)	0.4, 0.5, 0.65, 0.9 mm paper ($\mu\text{mho}/\text{km}$)	0.32 mm polyethylene ($\mu\text{mho}/\text{km}$)	0.4, 0.5, 0.65, 0.9 mm polyethylene ($\mu\text{mho}/\text{km}$)
0.00	0.00	0.00	0.00
2.50	19.64	0.31	0.39
10.00	78.54	1.26	1.57
20.00	157.08	2.51	3.14
30.00	235.62	3.77	4.71
40.00	314.16	5.03	6.28
50.00	392.70	6.28	7.85
100.00	785.40	12.57	15.71
150.00	1178.10	18.85	23.56
200.00	1570.80	25.13	31.42
250.00	1963.50	31.42	39.27
300.00	2356.19	37.70	47.12
350.00	2748.89	43.98	54.98
400.00	3141.59	50.27	62.83
450.00	3534.29	56.55	70.69
500.00	3926.99	62.83	78.54
550.00	4319.69	69.12	86.39
600.00	4712.39	75.40	94.25
650.00	5105.09	81.68	102.10
700.00	5497.79	87.96	109.96
750.00	5890.49	94.25	117.81
800.00	6283.19	100.53	125.66
850.00	6675.88	106.81	133.52
900.00	7068.58	113.10	141.37
950.00	7461.28	119.38	149.23
1000.00	7853.98	125.66	157.08
1050.00	8246.68	131.95	164.93
1100.00	8 639.38	138.23	172.79