表 C.22　実験結果 5.3-3

f[Hz]	ω[rad/s]	V[V]	I[mA]	λ[ms]	Z=V/I[Ω]	位相差[deg]
10	62.832	0.0001	16.0	-17	0.00625	-61.2
20	125.66	0.0001	17.0	-9.1	0.00588	-65.5
50	314.16	0.0004	17.0	-4.4	0.0235	-79.2
100	628.32	0.0008	17.0	-2.35	0.0471	-84.6
200	1256.6	0.0016	17.0	-1.210	0.0941	-87.1
500	3141.6	0.0041	17.0	-0.490	0.241	-88.2
1000	6283.2	0.0080	17.0	-0.248	0.471	-89.3
2000	12566	0.0160	17.0	-0.125	0.941	-90.0
5000	31416	0.0395	17.0	-0.0495	2.32	-89.1
10000	62832	0.098	17.0	-0.0248	5.76	-89.3
20000	125664	0.153	17.0	-0.0125	9.00	-90.0
50000	314159	0.375	17.0	-0.0050	22.1	-90.0
100000	628319	0.74	17.0	-0.00252	43.5	-90.7
200000	1256637	1.46	16.5	-0.00126	88.5	-90.7
500000	3141593	3.60	15.0	-0.000515	240	-92.7
1000000	6283185	6.7	9.5	-0.000230	705	-82.8
1390000	8733628	7.5	4.0	0.000142	1875	71.1

表 C.23　実験 5.3-1　式(5.7)による理論値

f[Hz]	ω[rad/s]	インピーダンス Z[Ω]	位相差[deg]
10	62.832	0.0908	-17.31
20	125.664	0.1022	-31.93
50	314.159	0.1605	-57.31
100	628.319	0.2837	-72.21
200	1256.637	0.5473	-80.88
500	3141.593	1.3537	-86.33
1000	6283.185	2.7032	-88.16
2000	12566.37	5.4043	-89.08
5000	31415.93	13.5100	-89.63
10000	62831.85	27.0244	-89.82
20000	125663.7	54.0884	-89.91
50000	314159.3	135.9191	-89.96
100000	628318.5	276.9470	-89.98
200000	1256637	598.9160	-89.99
500000	3141593	3473.8360	-89.99
1000000	6283185	1870.3793	90.00

表 C.24　実験 5.3-2　式(5.7)による理論値

f[Hz]	ω[rad/s]	インピーダンス Z[Ω]	位相差[deg]
10	62.832	0.1009	-35.41
20	125.664	0.1429	-54.88
50	314.159	0.3035	-74.29
100	628.319	0.5901	-81.99
200	1256.637	1.1716	-85.98
500	3141.593	2.9228	-88.39
1000	6283.185	5.8440	-89.19
2000	12566.37	11.6873	-89.60
5000	31415.93	29.2207	-89.84
10000	62831.85	58.4639	-89.92
20000	125663.7	117.1098	-89.96
50000	314159.3	295.9990	-89.98
100000	628318.5	616.2377	-89.99
200000	1256637	1473.8700	-89.99
500000	3141593	9930.8939	89.99
1000000	6283185	1399.0029	90.00

表 C.25　実験 5.3-3　式(5.7)による理論値

f[Hz]	ω[rad/s]	インピーダンス Z[Ω]	位相差[deg]
10	62.832	0.0050	-62.50
20	125.664	0.0091	-75.41
50	314.159	0.0221	-84.06
100	628.319	0.0440	-87.02
200	1256.637	0.0880	-88.51
500	3141.593	0.2199	-89.40
1000	6283.185	0.4398	-89.70
2000	12566.37	0.8797	-89.85
5000	31415.93	2.1992	-89.94
10000	62831.85	4.3985	-89.97
20000	125663.7	8.7989	-89.99
50000	314159.3	22.0293	-89.99
100000	628318.5	44.2895	-90.00
200000	1256637	90.4749	-90.00
500000	3141593	266.0463	-90.00
1000000	6283185	1435.6213	-90.00

表 C.26　実験 5.1-3　式(5.11)～(5.18)による理論値

f[Hz]	ω[rad/s]	ゲイン[dB]	位相差[deg]
1	6.283	-0.063594003	-0.13397596
3	18.850	-0.059326159	-0.402194524
10	62.832	-0.010656613	-1.350818581
30	188.496	0.427143041	-4.335635881
100	628.319	6.703033694	-37.86747431
300	1884.956	-13.85888503	-156.6790668
1000	6283.185	-34.38830635	-140.3720191
3000	18849.556	-47.7058994	-112.7930362
10000	62831.853	-58.88623845	-96.23794049
30000	188495.559	-68.502027	-89.13794001
100000	628318.531	-79.01744084	-79.78157276
300000	1884956	-89.39600446	-60.11569193
1000000	6283185	-88.98519567	152.3783127
3000000	18849556	-66.6280433	169.3584856
10000000	62831853	-45.42703595	174.1208084
30000000	188495559	-26.03750859	169.9204287
100000000	628318531	-2.200177085	132.2024003
300000000	1884955592	1.379833472	21.68591549
1000000000	6283185307	0.123489437	5.498956448

表 C.27　実験 5.1-6　式(5.11)～(5.18)による理論値

f[Hz]	ω[rad/s]	ゲイン[dB]	位相差[deg]
1	6.283	-0.025117678	-0.012009141
3	18.850	-0.024861256	-0.03602899
10	62.832	-0.021943946	-0.120156113
30	188.496	0.003743794	-0.362042189
100	628.319	0.301254235	-1.268731527
300	1884.956	3.451319216	-6.230893626
1000	6283.185	-8.771594057	-167.9479705
3000	18849.556	-29.9384107	-161.9087195
10000	62831.853	-48.56091221	-134.6083926
30000	188495.559	-60.79151821	-106.4930426
100000	628318.531	-71.81495191	-88.20850132
300000	1884956	-82.76658151	-70.07447347
1000000	6283185	-84.05496285	142.535768
3000000	18849556	-62.45760441	165.3031379
10000000	62831853	-41.34658971	173.8261115
30000000	188495559	-21.6762186	172.6063373
100000000	628318531	7.617117046	114.5224394
300000000	1884955592	1.125842281	8.084983099
1000000000	6283185307	0.096386812	2.142564465

表 C.28　実験 5.1-7　式(5.11)～(5.18)による理論値

f[Hz]	ω[rad/s]	ゲイン[dB]	位相差[deg]
1	6.283	-0.023844845	-0.011305328
3	18.850	-0.02383424	-0.033916029
10	62.832	-0.023713606	-0.113055069
30	188.496	-0.022653039	-0.339208482
100	628.319	-0.010582455	-1.132338144
300	1884.956	0.096058482	-3.44092169
1000	6283.185	1.376366484	-13.40980743
3000	18849.556	1.820642495	-132.7461394
10000	62831.853	-24.2949057	-172.817511
30000	188495.559	-43.84447037	-177.0974823
100000	628318.531	-65.48944241	-176.9484202
300000	1884956	-92.27002058	-169.9054016
1000000	6283185	-84.74523892	170.0425878
3000000	18849556	-61.32018127	176.9701505
10000000	62831853	-39.89983287	177.1029697
30000000	188495559	-20.10207206	172.5993995
100000000	628318531	8.431898338	88.8768135
300000000	1884955592	0.92886831	8.053048786
1000000000	6283185307	0.080330701	2.183675398

表 C.29　実験 5.1-8　式(5.11)～(5.18)による理論値

f[Hz]	ω[rad/s]	ゲイン[dB]	位相差[deg]
1	6.283	-0.000665103	-0.000846619
3	18.850	-0.000664208	-0.002539858
10	62.832	-0.000654029	-0.008466203
30	188.496	-0.000564542	-0.02539888
100	628.319	0.000453443	-0.084673159
300	1884.956	0.009407804	-0.254289527
1000	6283.185	0.111907149	-0.858003002
3000	18849.556	1.068043794	-2.882894419
10000	62831.853	9.469452522	-152.9091278
30000	188495.559	-20.62536219	-176.8663725
100000	628318.531	-42.56075322	-176.932876
300000	1884956	-64.9098224	-169.903912
1000000	6283185	-84.97064229	-9.955112905
3000000	18849556	-57.63504188	176.9687638
10000000	62831853	-34.93331829	177.0805971
30000000	188495559	-14.41692502	171.9854035
100000000	628318531	6.180811242	25.68815292
300000000	1884955592	0.530885529	4.311135087
1000000000	6283185307	0.046589444	1.221728539

フィルムコンデンサのデータシート 3)を添付する．

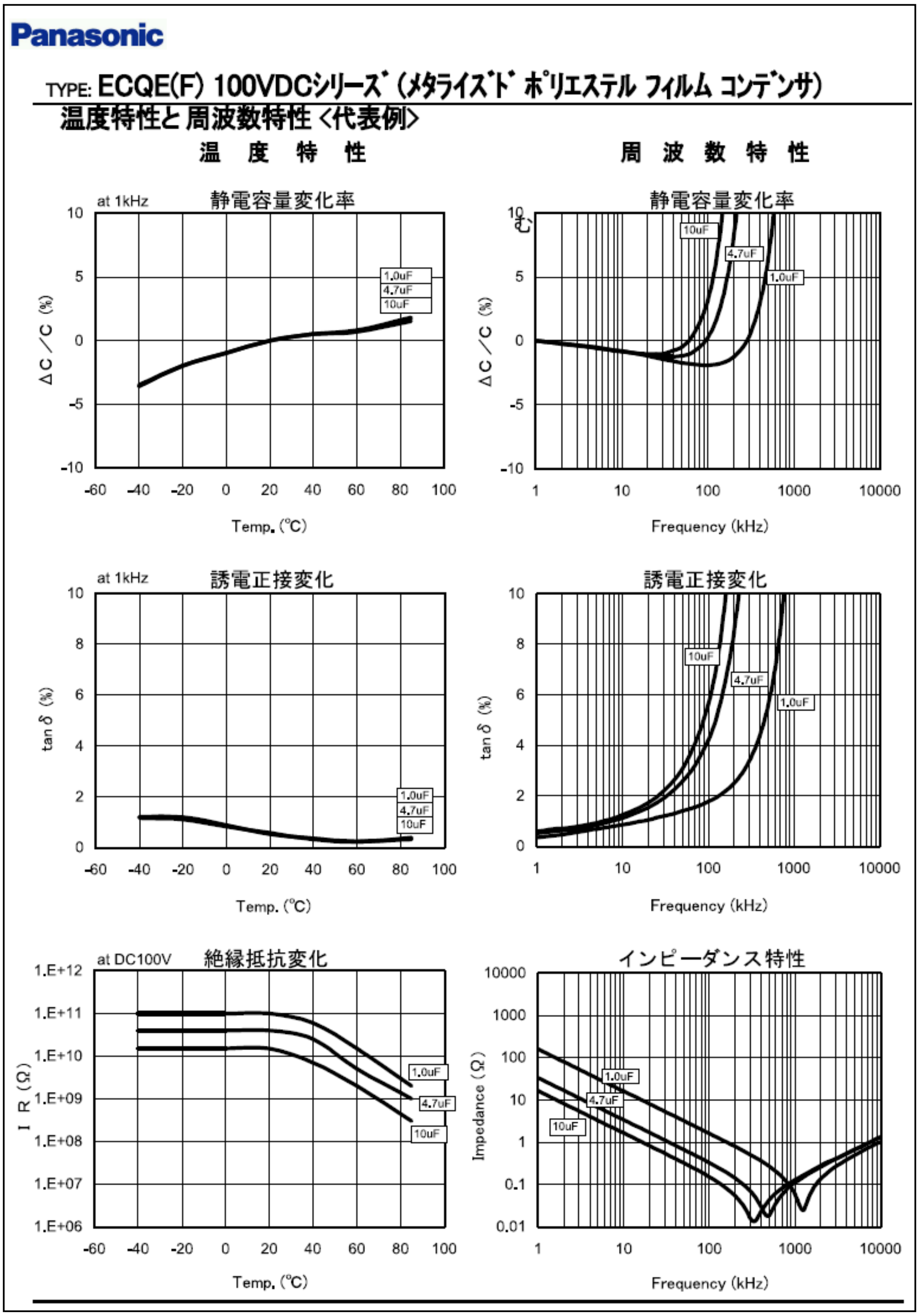
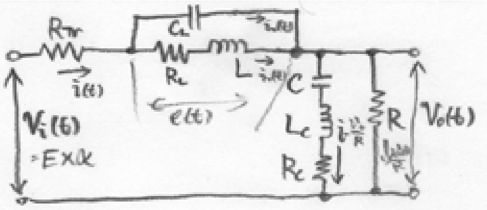


図 C.2　フィルムコンデンサデータシート

式(5.11)～(5.18)の導出過程を示す.



R_{Tr}を考慮する. ①

$$\begin{cases} v_i(t) = R_{Tr}\, i(t) + e(t) + v_o(t) \\ e(t) = R_L i_1(t) + L\dfrac{di_1(t)}{dt} = \dfrac{1}{C_L}\displaystyle\int_0^t i_2(t)dt \\ i(t) = i_1(t) + i_2(t) \\ v_o(t) = \dfrac{1}{C}\displaystyle\int_0^t \left(i(t) - \dfrac{v_o(t)}{R}\right)dt + L_c\dfrac{d}{dt}\left(i(t) - \dfrac{v_o(t)}{R}\right) + R_c\left(i(t) - \dfrac{v_o(t)}{R}\right) \end{cases}$$

ラプラス変換

$$\begin{cases} V_i(s) = R_{Tr} I(s) + E(s) + V_o(s) \quad \text{— ①} \\ E(s) = R_L I_1(s) + Ls I_1(s) = \dfrac{1}{C_L s} I_2(s) \quad \text{— ②} \\ I(s) = I_1(s) + I_2(s) \quad \text{— ③} \\ V_o(s) = \left(\dfrac{1}{Cs} + L_c s + R_c\right)\left(I(s) - \dfrac{V_o(s)}{R}\right) \quad \text{— ④} \end{cases}$$

$$① \rightarrow V_i(s) - V_o(s) - R_{Tr} I(s) = E(s) \quad \text{— ①'}$$

①'に②を代入して.

$$\left.\begin{aligned} &(a)\quad V_i(s) - V_o(s) - R_{Tr} I(s) = (Ls + R_L) I_1(s) \\ &\qquad I_1(s) = (V_i(s) - V_o(s) - R_{Tr} I(s)) \frac{1}{Ls + R_L} \\ &(b)\quad V_i(s) - V_o(s) - R_{Tr} I(s) = \frac{1}{C_L s} I_2(s) \\ &\qquad I_2(s) = (V_i(s) - V_o(s) - R_{Tr} I(s))\, C_L s \end{aligned}\right\} ②'$$

③に②'を代入して.

$$I(s) = (V_i(s) - V_o(s) - R_{Tr} I(s))\left(\frac{1}{Ls + R_L} + C_L s\right) \quad \text{③'}$$

$$, \quad X = \frac{1}{Ls + R_L} + C_L s = \frac{x_n}{x_d} = \frac{LC_L s^2 + R_L C_L s + 1}{Ls + R_L} \quad \text{とおく.}$$

$$(1 + XR_{Tr}) I(s) = XV_i(s) - XV_o(s)$$

$$I(s) = \frac{X}{1 + XR_{Tr}} V_i(s) - \frac{X}{1 + XR_{Tr}} V_o(s) \quad \text{— ③''}$$

④に③''を代入して.

$$V_o(s) = \left(\frac{1}{Cs} + L_c s + R_c\right)\left(\frac{X}{1 + XR_{Tr}} V_i(s) - \frac{X}{1 + XR_{Tr}} V_o(s) - \frac{V_o(s)}{R}\right)$$

$$= Y\left(\frac{X}{1 + XR_{Tr}} V_i(s) - \frac{XR + 1 + XR_{Tr}}{R + XR_{Tr}R} V_o(s)\right)$$

$$Y = \frac{1}{Cs} + L_c s + R_c, \quad \frac{y_n}{y_d} = \frac{CL_c s^2 + R_c Cs + 1}{Cs} \quad \text{とおく}$$

$$\left(1 + \frac{XR + 1 + XR_{Tr}}{R + XR_{Tr}R} \times Y\right) V_o(s) = \frac{XY}{1 + XR_{Tr}} V_i(s)$$

$$\rightarrow G_{LC}(s) = \frac{V_o(s)}{V_i(s)}$$

$$\rightarrow G_{LC}(s) = \frac{V_o(s)}{V_i(s)}$$

$$= \frac{\dfrac{XY}{1+XR_{Tr}}}{\dfrac{R+XR_{Tr}R+XYR+Y+XYR_{Tr}}{R+XR_{Tr}R}}$$

$$= \frac{XY}{1+XR_{Tr}} \cdot \frac{R(1+XR_{Tr})}{R+XR_{Tr}R+XYR+Y+XYR_{Tr}}$$

$$= \frac{XYR}{R+XR_{Tr}R+XYR+Y+XYR_{Tr}}$$

$$= \frac{XYR}{XY(R+R_{Tr})+XRR_{Tr}+Y+R}$$

ここで.

$$XY = \frac{LC_L s^2+R_L C_L s+1}{Ls+R_L} \cdot \frac{CL_c s^2+R_c Cs+1}{Cs} = \frac{x_n}{x_d} \cdot \frac{y_n}{y_d}$$

$$x_n y_n = (LC_L s^2+R_L C_L s+1)(CL_c s^2+R_c Cs+1)$$

$$= LL_c CC_L s^4 + LCC_L R_c s^3 + LC_L s^2 + L_c CC_L R_L s^3 + CC_L R_L R_c s^2 + R_L C_L s + CL_c s^2 + R_c Cs + 1$$

$$= LL_c CC_L s^4 + CC_L(LR_c+L_c R_L)s^3 + (LC_L+CC_L R_L R_c+CL_c)s^2 + (R_L C_L+R_c C)s + 1$$

$$= as^4 + bs^3 + ds^2 + fs + g$$

$$x_d y_d = LCs^2 + CR_L s = hs^2 + ks + m$$

$$x_d y_n = (Ls+R_L)(CL_c s^2+R_c Cs+1)$$

$$= LL_c Cs^3 + (LCR_c+L_c CR_L)s^2 + (L+CR_L R_c)s + R_L$$

$$= ns^3 + os^2 + ps + q$$

$$x_n y_d = (LC_L s^2+R_L C_L s+1)\cdot Cs$$

$$= LCC_L s^3 + CC_L R_L s^2 + Cs = ts^3 + us^2 + ws$$

$$\rightarrow G_{LC}(s) = \frac{\dfrac{x_n y_n}{x_d y_d}R}{\dfrac{x_n}{x_d}\cdot\dfrac{y_n}{y_d}(R+R_{Tr}) + \dfrac{x_n}{x_d}RR_{Tr} + \dfrac{y_n}{y_d} + R}$$

$$= \frac{\dfrac{1}{x_d y_d}\cdot x_n y_n R}{\dfrac{1}{x_d y_d}\left\{x_n y_n(R+R_{Tr}) + x_n y_d RR_{Tr} + x_d y_n + x_d y_d R\right\}}$$

$$= \frac{x_n y_n R}{x_n y_n(R+R_{Tr}) + x_n y_d RR_{Tr} + x_d y_n + x_d y_d R}$$

$$= \frac{(as^4+bs^3+ds^2+fs+g)R}{(as^4+bs^3+ds^2+fs+g)(R+R_{Tr}) + (ts^3+us^2+ws)RR_{Tr} + (ns^3+os^2+ps+q) + (hs^2+ks+m)R}$$

$$= \frac{aRs^4+bRs^3+dRs^2+fRs+gR}{a(R+R_{Tr})s^4 + \{b(R+R_{Tr})+tRR_{Tr}+n\}s^3 + \{d(R+R_{Tr})+uRR_{Tr}+o+hR\}s^2 + \{f(R+R_{Tr})+wRR_{Tr}+p+kR\}s + \{g(R+R_{Tr})+q+mR\}}$$

$$= \frac{As^4-Es^3-Bs^2+Fs+D}{Hs^4-Ns^3-Ks^2+Os+M}$$

$G_{ic}(j\omega)$を計算する.

$s = j\omega$, $s^2 = -\omega^2$, $s^3 = -j\omega^3$, $s^4 = \omega^4$

$$(分子) = (a\omega^4 - d\omega^2 + g)R + j(-b\omega^3 + f\omega)R = (\underset{aR}{A}\omega^4 + \underset{-dR}{B}\omega^2 + D) + j(\underset{-bR}{E}\omega^3 + F\omega) = T + jU$$

$$(分母) = \Big[\underbrace{a(R+R_{Tr})}_{H}\omega^4 \underbrace{- \{d(R+R_{Tr}) + uRR_{Tr} + o + hR\}}_{K}\omega^2 + \underbrace{\{g(R+R_{Tr}) + q + mR\}}_{M}\Big]$$
$$+ j\Big[\underbrace{-\{b(R+R_{Tr}) + tRR_{Tr} + n\}}_{N}\omega^3 + \underbrace{\{f(R+R_{Tr}) + wRR_{Tr} + p + kR\}}_{O}\omega\Big]$$
$$= (H\omega^4 + K\omega^2 + M) + j(N\omega^3 + O\omega)$$
$$= V + jW$$

$$\rightarrow G_{ic}(j\omega) = \frac{T + jU}{V + jW}$$
$$= \frac{1}{V^2 + W^2}\{(VT + WU) + j(VU - WT)\}$$
$$= \frac{1}{V^2 + W^2}\sqrt{V^2T^2 + V^2U^2 + W^2T^2 + W^2U^2}$$

ゲイン：$g = 20\log_{10}\left|\frac{1}{V^2+W^2}\sqrt{V^2T^2 + V^2U^2 + W^2T^2 + W^2U^2}\right|$

位相差：$\varphi = \tan^{-1}\frac{VU - WT}{VT + WU}$

$$\begin{cases} T_{(\omega)} = A\omega^4 + B\omega^2 + D \\ U_{(\omega)} = E\omega^3 + F\omega \\ V_{(\omega)} = H\omega^4 + K\omega^2 + M \\ W_{(\omega)} = N\omega^3 + O\omega \end{cases}$$

$$\begin{cases} A = aR \\ B = -dR \\ D = gR \\ E = -bR \\ F = fR \\ H = a(R+R_{Tr}) \\ K = -\{d(R+R_{Tr}) + uRR_{Tr} + o + hR\} \\ M = g(R+R_{Tr}) + q + mR \\ N = -\{b(R+R_{Tr}) + tRR_{Tr} + n\} \\ O = f(R+R_{Tr}) + wRR_{Tr} + p + kR \end{cases}$$

$$\begin{cases} a = LL_cCC_L \\ b = CC_L(LR_c + L_cR_L) \\ d = LC_L + CC_LR_LR_c + CL_c \\ f = R_LC_L + R_cC \\ g = 1 \\ h = LC \\ k = CR_L \\ m = 0 \end{cases}$$

$$\begin{cases} n = LL_cC \\ o = LCR_c + L_cCR_L \\ p = L + CR_LR_c \\ q = R_L \\ t = LCC_L \\ u = CC_LR_L \\ w = C \end{cases}$$