Second Semester Examination
2018/2019 Academic Session

June 2019

EEE354 – Digital Control Systems
(Sistem Kawalan Digit)

Duration : 3 hours
(Masa : 3 jam)

Please ensure that this examination paper consists of NINE (9) pages and SIX (6) pages of printed appendix material before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi SEMBILAN (9) muka surat dan ENAM (6) muka surat lampiran yang bercetak sebelum anda memulakan peperiksaan ini.]

Instruction: This question paper consists of **FIVE (5)** questions. Answer **ALL** questions. All questions carry the same marks.

***[Arahan:** Kertas soalan ini mengandungi **LIMA (5)** soalan. Jawab **SEMUA** soalan. Semua soalan membawa jumlah Markah yang sama.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai.]

1. (a) A signal $f(t)$ is sampled by the ideal sampler as shown in Figure 1(a). List the conditions under which a signal $f(t)$ can be fully recovered from $f^*(t)$.

Suatu isyarat $f(t)$ disampel oleh pensampel unggul seperti ditunjukkan dalam Rajah 1(a). Senaraikan keadaan dimana isyarat $f(t)$ boleh dipulihkan sepenuhnya daripada $f^*(t)$.

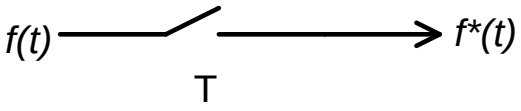

Figure 1(a)
Rajah 1(a)

(20 marks/*markah*)

(b) For a function $f(t)$, derive a relationship between its starred transform $F^*(s)$ and its z transform $F(z)$. Include any sketches if necessary.

Bagi fungsi $f(t)$, carikan hubungan antara jelmaan bintang $F^*(s)$ dan jelmaan z $F(z)$. Masukkan sebarang lakaran jika perlu.

(20 marks/*markah*)

(c) The z transform of a function is given by:-

Jelmaan z bagi suatu fungsi diberi oleh:-

$$F(z) = \frac{z}{(z-1)(z-2)}$$

Find the inverse z transform of this function.

Carikan jelmaan songsang z bagi fungsi tersebut.

Now consider the function $F_1(z)$ where:-

Sekarang pertimbangkan fungsi $F_1(z)$ dimana:-

…3/-

$$F_1(z) = z^{-1}F(z)$$

By stating any assumptions made, find the inverse z transform of $F_1(z)$.

Dengan menyatakan sebarang andaian dibuat, carikan jelmaan songsang z bagi $F_1(z)$*.*

(30 marks/*markah*)

(d) A system is described as linear if the principle of superposition applies. Figure 1(b) shows a sampler/ZOH device. Is the sampler/zero order hold device linear?

Suatu sistem diperihalkan sebagai lelurus sekiranya prinsip tindihan terpakai. Rajah 1(a) menunjukkan peranti pensamel/ZOH. Adakah peranti pensampel/ZOH peranti lelurus?

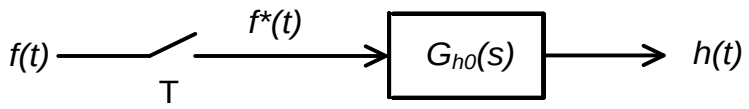

Figure 1(b)

Rajah 1(b)

(30 marks/*markah*)

2. A system is described by the following equations:-

Suatu sistem diperihalkan dengan persamaan-persamaan berikut:-

$$y[k+2] - \frac{3}{4}y[k+1] + \frac{1}{8}y[k] = x[k]$$

$$y(0) = y(1) = 0$$

$$x(k) = \begin{cases} 0, & k = 0 \\ 1, & k \geq 1 \end{cases}$$

(a) By stating any assumptions made and using the z transform method, solve $y[k]$ for $0 \leq k \leq 4$.

Dengan menyatakan sebarang andaian yang dibuat dan menggunakan kaedah jelmaan z, selesaikan $y[k]$ *untuk* $0 \leq k \leq 4$*.*

(40 marks/*markah*)

(b) Justify your answer in (a) by using the sequential method.

Tentusahkan jawapan anda di (a) menggunakan kaedah jujukan.

(30 marks/*markah*)

(c) Sketch the simulation diagram of the system.

Lakarkan gambarajah simulasi sistem tersebut.

(10 marks/*markah*)

(d) Will the final value theorem give the correct value of $y(k)$ as $k \to \infty$? Proof this.

Adakah teori nilai akhir akan memberikan nilai yang betul utk $y(k)$ *bagi* $k \to \infty$*? Buktikan.*

(20 marks/*markah*)

3**.** An open loop system is shown in Figure 3(a).

Suatu sistem gelung terbuka ditunjukkan dalam Rajah 3(a).

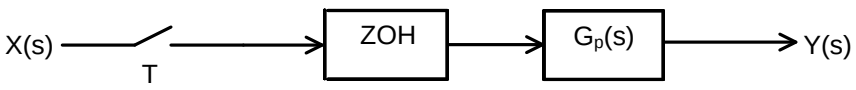

Figure 3(a)

Rajah 3(a)

(a) By stating any assumptions made, derive the pulse transfer function, $\frac{Y(z)}{X(z)}$ of the discrete-time system, if,

Dengan menyatakan sebarang andaian yang dibuat, terbitkan rangkap pindah $\frac{Y(z)}{X(z)}$ *bagi sistem diskret-masa tersebut, jika,*

$$G_p(s) = \frac{2s}{s+4}$$

(30 marks/*markah*)

(b) By stating any assumptions made, determine the system time response at the sampling interval for:-

Dengan menyatakan sebarang andaian yang dibuat tentukan sambutan masa sistem tersubut pada kala pensampelan bagi:-

(i) Unit ramp input
Masukan unit rampa

(ii) Unit step input
Masukan unit langkah

(30 marks/*markah*)

(c) Determine the pulse transfer function of the system using the modified z transform if;

Tentukan fungsi pindah dedenyut sistem tersebut menggunakan jelmaan z terubahsuai jika;

$$G_p(s) = G_n(s) = \frac{2se^{-0.7}}{s+4}$$

(20 marks/*markah)*

…6/-

(d) The system in Figure 3(a) is subjected to a closed loop as shown in Figure 3(b). Find the pulse transfer function if:

Sistem di Rajah 3(a) dikenakan gelung tertutup seperti ditunjukkan dalam Rajah 3(b). Carikan rangkap pindah dedenyut jika:

$$H(s) = \frac{1}{1 - e^{-s}}$$

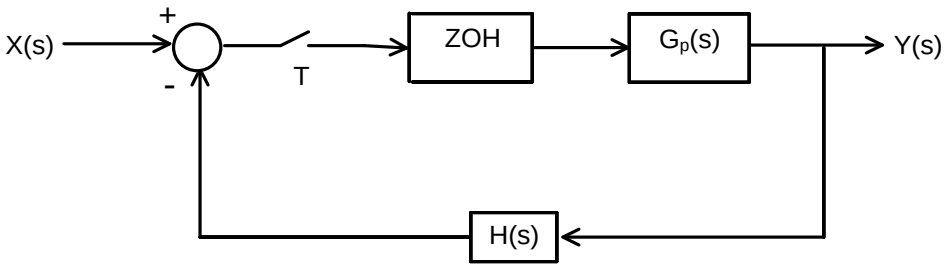

Figure 3 (b)

Rajah 3 (b)

(20 marks/*markah*)

4. (a) Consider a system with the following blok diagram.

Pertimbangkan sistem yang bergambarajah blok berikut:-

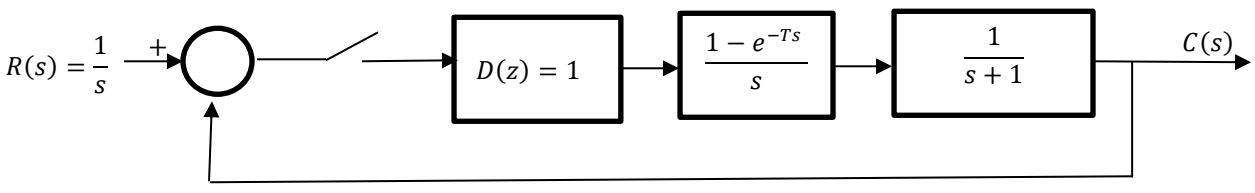

Figure 4

Rajah 4

(i) Assuming $T = 1\ sec$, determine the closed-loop transfer function of the system.

Andaikan $T = 1\ saat$, tentukan fungsi pindah gelung tertutup sistem tersebut.

(20 marks/*markah*)

(ii) For $T = 0.5\ sec, 1\ sec$ and $2\ sec$, plot the system's unit step response (on the same figure), and discuss the effect of increasing T on system steady-state error e_{ss}.

Untuk $T = 0.5\ saat, 1\ saat$ dan $2\ saat$, lakarkan sambutan unit langkah (dalam rajah yang sama) bagi sistem tersebut dan bincangkan kesan menaik T kepada ralat keadaan mantap e_{ss}.

(30 marks/*markah*)

(b) Given the following closed-loop transfer function:-

Diberi rangkap pindah gelung tertutup berikut:-

$$G(z) = \frac{(T - 1 + e^{-T})z + (1 - e^{-T} - Te^{-T})}{(z - 1)(z - e^{-T})}$$

(i) Compute the damping ratio ζ, natural frequency w_n and time constant τ, for $T = 1\ sec$.

Kirakan nisbah redaman ζ, frekuensi tabii w_n dan pemalar masa τ, bagi $T = 1\ saat$.

(20 marks/*markah*)

(ii) Repeat part (i) for $T = 0.5\ sec$ and $1\ sec$, and state the effect of decreasing the sampling rate on system parameters (ζ, w_n and τ).

Ulangi bahagian (i) untuk $T = 0.5\ saat$ dan $1\ saat$, dan nyatakan kesan menurunkan kadar pensampelan kepada parameter-parameter sistem (ζ, w_n dan τ).

(30 marks/*markah*)

…8/-

5. (a) A robot arm joint system is shown in Figure 5 where:-

Suatu sistem sendi lengan robot ditunjukkan dalam Rajah 5 dimana:-

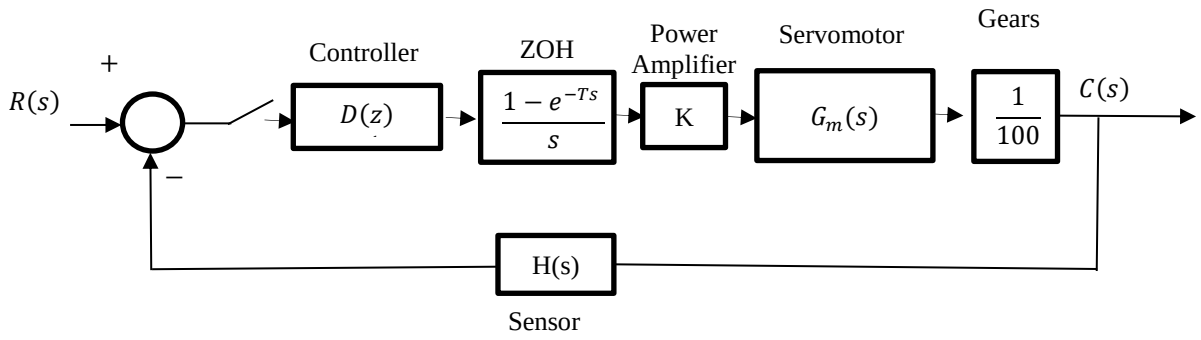

Figure 5

Rajah 5

$$H(s) = 0.7$$

$$D(z) = 1$$

$$R(s) = \frac{1}{s}$$

$$G_m(s) = \frac{200}{s(0.5s + 1)}$$

$$T = 0.1\ sec$$

(i) Write the closed-loop system characteristic equation.

Tuliskan persamaan ciri bagi sistem tertutup tersebut.

(20 marks/*markah*)

(ii) Use Jury test to check system stability.

Gunakan ujian Jury untuk menyemak kestabilan sistem.

(20 marks/*markah*)

(iii) Sketch the z-plane of root locus.

Lakarkan satah z bagi londar punca.

(20 marks/*markah*)

(b) Assuming $T = 0.05\ sec$, consider the following open-loop transfer function of a discrete-time system:-

Andaikan $T = 0.05\ saat$, pertimbangkan rangkap pindah gelung terbuka bagi sistem diskret-masa berikut:-

$$G(z) = \frac{0.02267\ z + 0.02053}{(z-1)(z-0.7408)}$$

(i) Sketch the Bode diagram for the system.

Lakarkan gambarajah Bode bagi sistem tersebut.

(20 marks/*markah*)

(ii) Discuss system's stability and compute **phase-cross over frequency**, **gain-cross over frequency**, **gain margin**, and **phase margin**.

*Bincangkan kestabilan sistem dan kirakan **frekuensi silang fasa**, **frekuensi silang gandaan**, **jidar gandaan** dan **jidar fasa**.*

(20 marks/*markah*)

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APPENDIX A

LAMPIRAN A

z transform of common functions

	$F(s)$	$f(t)$	$f(kT)$	$F(z)$
1.			$\delta_0(k)$ $1, \quad k = 0$ $0, \quad k \neq 0$	1
2.			$\delta_0(n-k)$ $1, \quad n = k$ $0, \quad n \neq k$	$\frac{1}{z^k}$
3.	$\frac{1}{s}$	$1(t)$	$1(k)$	$\frac{z}{z-1}$
4.	$\frac{1}{(s+a)}$	e^{-at}	e^{-akT}	$\frac{z}{z-e^{-aT}}$
5.	$\frac{1}{s^2}$	t	kT	$\frac{Tz}{(z-1)^2}$
6.	$\frac{2}{s^3}$	t^2	$(kT)^2$	$\frac{T^2z(z+1)}{(z-1)^3}$
7.	$\frac{6}{s^4}$	t^3	$(kT)^3$	$\frac{T^3z(z^2+4z+1)}{(z-1)^4}$
8.	$\frac{a}{s(s+a)}$	$1-e^{-at}$	$1-e^{-akT}$	$\frac{z(1-e^{-aT})}{(z-1)(z-e^{-aT})}$
9.	$\frac{b-a}{(s+a)(s+b)}$	$e^{-at}-e^{-bt}$	$e^{-akT}-e^{-bkT}$	$\frac{z(e^{-aT}-e^{-bT})}{(z-e^{-aT})(z-e^{-bT})}$
10.	$\frac{1}{(s+a)^2}$	te^{-at}	kTe^{-akT}	$\frac{Te^{-aT}z}{(z-e^{-aT})^2}$
11.	$\frac{s}{(s+a)^2}$	$(1-at)e^{-at}$	$(1-akT)e^{-akT}$	$\frac{z^2-(1+aT)e^{-aT}z}{(z-e^{-aT})^2}$
12.	$\frac{2}{(s+a)^3}$	t^2e^{-at}	$(kT)^2e^{-akT}$	$\frac{T^2e^{-aT}(z+e^{-aT})z}{(z-e^{-aT})^3}$
13.	$\frac{a}{s^2(s+a)}$	$t-\frac{1-e^{-at}}{a}$	$kT-\frac{1-e^{-akT}}{a}$	$\frac{z[(aT-1+e^{-aT})z+(1-e^{-aT}-aTe^{-aT})]}{a(z-1)^2(z-e^{-aT})}$
14.	$\frac{a^2}{s^2(s+a)}$	$at-1+e^{-at}$	$akT-1+e^{-akT}$	$\frac{z(aT-1+e^{-aT})+(1-e^{-aT}-aTe^{-aT})}{(z-1)(z-e^{-aT})}$

z transform of common functions - continued

	$F(s)$	$f(t)$	$f(kT)$	$F(z)$
15.	$\frac{a^2}{s(s+a)^2}$	$1-(1+at)e^{-at}$	$1-(1+akT)e^{-akT}$	$\frac{z}{z-1}-\frac{z}{z-e^{-aT}}-\frac{aTe^{-aT}z}{(z-e^{-aT})^2}$
16.	$\frac{\omega}{s^2+\omega^2}$	$\sin\omega t$	$\sin\omega kT$	$\frac{z\sin\omega T}{z^2-2z\cos\omega T+1}$
17.	$\frac{s}{s^2+\omega^2}$	$\cos\omega t$	$\cos\omega kT$	$\frac{z(z-\cos\omega T)}{z^2-2z\cos\omega T+1}$
18.	$\frac{1}{(s+a)^2+\beta^2}$	$\frac{1}{\beta}e^{-at}\sin\beta t$	$\frac{1}{\beta}e^{-akT}\sin\beta kT$	$\frac{1}{\beta}\left[\frac{ze^{-aT}\sin\beta T}{z^2-2ze^{-aT}\cos\beta T+e^{-2aT}}\right]$
19.	$\frac{s+a}{(s+a)^2+\omega^2}$	$e^{-at}\cos\omega t$	$e^{-akT}\cos\omega kT$	$\frac{z(z-e^{-aT}\cos\omega T)}{z^2-2ze^{-aT}\cos\omega T+e^{-2aT}}$
20.	$\frac{\omega^2+\beta^2}{s[(s+\omega)^2+\beta^2]}$	$1-e^{-\omega t}\left(\cos\beta t+\frac{\omega}{\beta}\sin\beta t\right)$	$1-e^{-\omega kT}\left(\cos\beta kT+\frac{\omega}{\beta}\sin\beta kT\right)$	$\frac{z(Az+B)}{(z-1)(z^2-2ze^{-\omega T}\cos\beta T+e^{-2\omega T})}$ $A=1-e^{-\omega T}\left(\cos\beta T+\frac{\omega}{\beta}\sin\beta T\right)$ $B=e^{-2\omega T}+e^{-\omega T}\left(\frac{\omega}{\beta}\sin\beta T-\cos\beta T\right)$
21.	$\frac{1}{s(s+a)(s+b)}$	$\frac{1}{ab}+\frac{e^{-at}}{a(a-b)}+\frac{e^{-bt}}{b(b-a)}$	$\frac{1}{ab}+\frac{e^{-akT}}{a(a-b)}+\frac{e^{-bkT}}{b(b-a)}$	$\frac{(Az+B)z}{(z-e^{-aT})(z-e^{-bT})(z-1)}$ $A=\frac{b(1-e^{-aT})-a(1-e^{-bT})}{ab(b-a)}$ $B=\frac{ae^{-aT}(1-e^{-bT})-be^{-bT}(1-e^{-aT})}{ab(b-a)}$
22.			a^k	$\frac{z}{z-a}$
23.			a^{k-1} $k=1,2,3,\cdots$	$\frac{1}{z-a}$
24.			ka^{k-1}	$\frac{z}{(z-a)^2}$
25.			k^2a^{k-1}	$\frac{z(z+a)}{(z-a)^3}$

z transform of common functions - continued

	$F(s)$	$f(t)$	$f(kT)$	$F(z)$
26.			k^3a^{k-1}	$\frac{z(z^2+4az+a^2)}{(z-a)^4}$
27.			k^4a^{k-1}	$\frac{z(z^3+11az^2+11a^2z+a^3)}{(z-a)^5}$
28.			$a^k \cos k\pi$	$\frac{z}{z+a}$

APPENDIX B
LAMPIRAN B

Modified z transforms of common functions

	$F(s)$	$f(t)$	$f(kT)$	$F(z)$	$F(z,m)$
1.	$\frac{1}{s}$	$1(t)$	$1(k)$	$\frac{z}{z-1}$	$\frac{1}{z-1}$
2.	$\frac{1}{(s+a)}$	e^{-at}	e^{-akT}	$\frac{z}{z-e^{-aT}}$	$\frac{e^{-amT}}{z-e^{-aT}}$
3.	$\frac{1}{s^2}$	t	kT	$\frac{Tz}{(z-1)^2}$	$\frac{mT}{z-1}+\frac{T}{(z-1)^2}$
4.	$\frac{2}{s^3}$	t^2	$(kT)^2$	$\frac{T^2z(z+1)}{(z-1)^3}$	$T^2\left[\frac{m^2}{z-1}+\frac{2m+1}{(z-1)^2}+\frac{2}{(z-1)^3}\right]$
5.	$\frac{a}{s(s+a)}$	$1-e^{-at}$	$1-e^{-akT}$	$\frac{z(1-e^{-aT})}{(z-1)(z-e^{-aT})}$	$\frac{1}{z-1}-\frac{e^{-amT}}{z-e^{-aT}}$
6.	$\frac{b-a}{(s+a)(s+b)}$	$e^{-at}-e^{-bt}$	$e^{-akT}-e^{-bkT}$	$\frac{z(e^{-aT}-e^{-bT})}{(z-e^{-aT})(z-e^{-bT})}$	$\frac{e^{-amT}}{z-e^{-aT}}-\frac{e^{-bmT}}{z-e^{-bT}}$
7.	$\frac{1}{(s+a)^2}$	te^{-at}	kTe^{-akT}	$\frac{Te^{-aT}z}{(z-e^{-aT})^2}$	$\frac{Te^{-amT}[e^{-aT}+m(z-e^{-aT})]}{(z-e^{-aT})^2}$
8.	$\frac{a}{s^2(s+a)}$	$t-\frac{1-e^{-at}}{a}$	$kT-\frac{1-e^{-akT}}{a}$	$\frac{z[(aT-1+e^{-aT})z+(1-e^{-aT}-aTe^{-aT})]}{a(z-1)^2(z-e^{-aT})}$	$\frac{T}{(z-1)^2}+\frac{amT-1}{a(z-1)}+\frac{e^{-amT}}{a(z-e^{-aT})}$
9.	$\frac{a^2}{s(s+a)^2}$	$1-(1+at)e^{-at}$	$1-(1+akT)e^{-akT}$	$\frac{z}{z-1}-\frac{z}{z-e^{-aT}}-\frac{aTe^{-aT}z}{(z-e^{-aT})^2}$	$\frac{1}{z-1}-\left[\frac{1+amT}{z-e^{-aT}}+\frac{aTe^{-aT}}{(z-e^{-aT})^2}\right]e^{-amT}$
10.	$\frac{\omega}{s^2+\omega^2}$	$\sin\omega t$	$\sin\omega kT$	$\frac{z\sin\omega T}{z^2-2z\cos\omega T+1}$	$\frac{z\sin\omega mT+\sin(1-m)\omega T}{z^2-2z\cos\omega T+1}$

11.	$\frac{s}{s^2+\omega^2}$	$\cos \omega t$	$\cos \omega kT$	$\frac{z(z-\cos \omega T)}{z^2-2z\cos \omega T+1}$	$\frac{z\cos \omega mT-\cos(1-m)\omega T}{z^2-2z\cos \omega T+1}$
12.	$\frac{1}{(s+a)^2+\beta^2}$	$\frac{1}{\beta}e^{-at}\sin \beta t$	$\frac{1}{\beta}e^{-akT}\sin \beta kT$	$\frac{1}{\beta}\left[\frac{ze^{-aT}\sin \beta T}{z^2-2ze^{-aT}\cos \beta T+e^{-2aT}}\right]$	$\frac{1}{\beta}\left[\frac{e^{-amT}[z\sin \beta mT+e^{-aT}\sin(1-m)\beta T]}{z^2-2ze^{-aT}\cos \beta T+e^{-2aT}}\right]$
13.	$\frac{s+a}{(s+a)^2+\omega^2}$	$e^{-at}\cos \omega t$	$e^{-akT}\cos \omega kT$	$\frac{z(z-e^{-aT}\cos \omega T)}{z^2-2ze^{-aT}\cos \omega T+e^{-2aT}}$	$\frac{e^{-amT}[z\cos \omega mT+e^{-aT}\sin(1-m)\omega T]}{z^2-2ze^{-aT}\cos \omega T+e^{-2aT}}$
14.	$\frac{\omega^2+\beta^2}{s[(s+\omega)^2+\beta^2]}$	$1-e^{-\omega t}\left(\cos \beta t+\frac{\omega}{\beta}\sin \beta t\right)$	$1-e^{-\omega kT}\left(\cos \beta kT+\frac{\omega}{\beta}\sin \beta kT\right)$	$\frac{z(Az+B)}{(z-1)(z^2-2ze^{-\omega T}\cos \beta T+e^{-2\omega T})}$ $A=1-e^{-\omega T}\left(\cos \beta T+\frac{\omega}{\beta}\sin \beta T\right)$ $B=e^{-2\omega T}+e^{-\omega T}\left(\frac{\omega}{\beta}\sin \beta T-\cos \beta T\right)$	$\frac{1}{z-1}$ $-\frac{e^{-\omega mT}[z\cos \beta mT+e^{-\omega T}\sin(1-m)\beta T]}{z^2-2ze^{-\omega T}\cos \beta T+e^{-2\omega T}}$ $+\frac{\omega}{\beta}\left\{\frac{e^{-\omega mT}[z\sin \beta mT-e^{-\omega T}\sin(1-m)\beta$
15.			a^k	$\frac{z}{z-a}$	$\frac{1}{z-a}$

APPENDIX C
LAMPIRAN C

$$z = \frac{-\ln r}{\sqrt{(\ln r)^2 + q^2}} \qquad w_n = \frac{1}{T}\sqrt{(\ln r)^2 + q^2} \qquad \tau = \frac{1}{\zeta \omega_n} = \frac{-T}{\ln r}$$