The Optimal Compensator for AT Forward Multi Resonant Converter

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Abstract

The alternated forward multi resonant converter (AT forward MRC) is studied on the transient response and the measured loop gain for stability. The compensator is composed of the error amplifier with 3 poles and 2 zeros. This is optimized through the experiment with HP4194A network analyzer. We are initiated by the thinking of how to make the stabilization from the experimental results of loop gain curves. The loop gain, low frequency gain and gain margin are more improved through the experimental considerations. Also, the transient response is more enhanced effectively.

1. Introduction

The DC-DC converters including multi resonant converters are considerably compensated using the error amplifiers in the negative feedback schemes for concerning of the output regulation and the transient characteristics [1][2]. The stability design is complemented using pole-zero compensation technique of the error amplifier. The optimally compensated AT forward MRC ratings are chosen as the input 48V, the output 5V/50W, the maximum operation frequency 2MHz[3]-[6]. When the input is 58V, the measured maximum voltage stress of 170V is 2.9 times the input voltage. The maximum efficiency is 81.66%. The stability analysis is accomplished using impedance/ gain-phase analyzer on the basis of the op amp compensation skills. In result, we found out that the 3-pole, 2-zero compensator is more suitable than the other compensators. The experimental circuit, the loop gains and the transient response, etc are discussed.

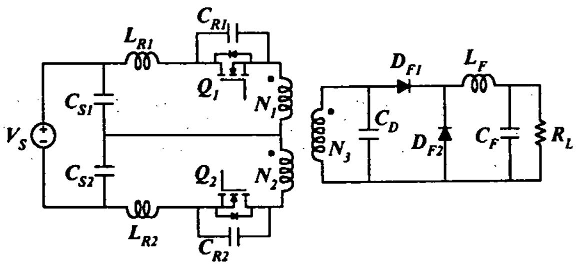


Fig. 1 AT forward MRC

2. The compensated AT forward MRC

2.1 The characteristics of the AT forward MRC

As shown in Fig.1, the AT forward zero voltage switching multi resonant converter is alternatively operated using two multi resonant switches with dead time. The design specifications and the experimental components are listed in Table 1 and Table 2.

Where, T is the transformer. N_1, N_2 is the primary turn ratio of the transformer. N_3 is the secondary turn ratio of the transformer. The control circuits are composed of the drive circuits and the resonant control IC, MC33067. The compensation circuit is constituted using the op amp in MC34067. Fig. 2 shows the experimental circuit for measuring the loop gains.

Table 1 The design specifications

Input (V_i)	$38V \sim 58V$
Output (V_o)	$5V$
Output current (i_o)	$10A$
Switching frequency (f_s)	$500KHz \sim 1MHz$
Maximum operating frequency	$2MHz$
Duty ratio (D)	$0.45 \sim 0.48$

Table 2 Experimental components

Circuit parameters		*Component values*
Primary switch (Q_1, Q_2)		*IRF640*
T	*Core*	*Mn-Zn ferrite core*
	Turns ratio(N)	*1.5*
	N_1, N_2	*3 Ts, USTC*
	N_3	*2 Ts, Cu foil*
	Leakage inductance	*520 nH (500KHz)* *490 nH (1MHz)*
Resonant inductor (L_{R1}, L_{R2})		*3 μH*
Resonant capacitor (C_{R1}, C_{R2})		*5.7 nF*
Rectifiers (D_{F1}, D_{F2})		*60CNQ035*
Input filter cap. (C_{S1}, C_{S2})		*22 μF*
Output filter cap. (C_F)		*22 μF*
Output filter ind. (L_F)		*24 μH*

2.2 The optimal compensator

At first, the error amplifier was built in 1-pole, 1-zero construction. In this paper, 3-pole, 2-zero compensated error amplifier is considered.. The 3-pole, 2-zero compensator expresses the characteristics of phase boost due to 2-zero such as f_{z1}, f_{z2}. that are located closely. It induces the increasing of phase margin. And also, the third pole, f_{p2} reduces the unnecessary gain at a high frequency. 1-pole, 1-zero compensator and 3-pole, 2-zero compensator are shown in Fig. 3 and Fig. 4, each other. the 1-pole, 1-zero compensator values are R_1=940Ω, R_2=2$K\Omega$, C_1=51nF, the 3-pole, 2-zero compensator values are R_1=47$K\Omega$, R_2=43$K\Omega$, R_3=10Ω, C_1=380pF, C_2=2pF, C_3=470pF.

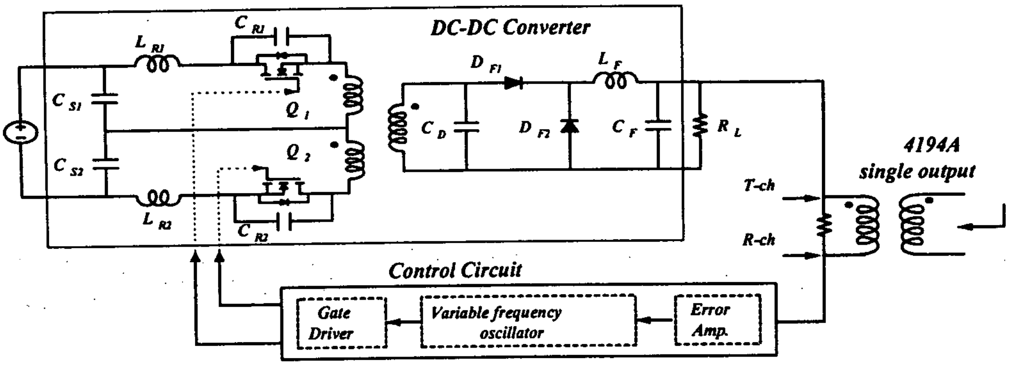


Fig. 2 Experimental circuit for measuring the loop gains

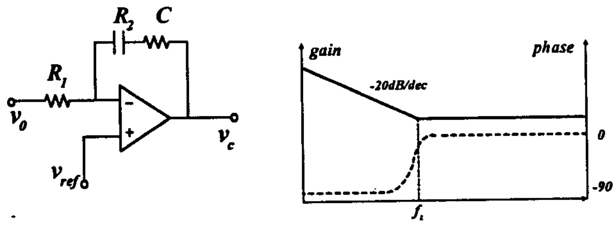


Fig. 3 1-pole, 1-zero type

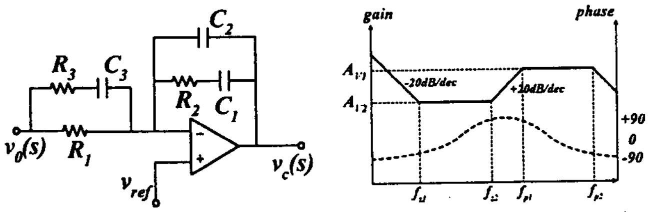


Fig. 4 3-pole, 2-zero type

The right side graphs are the gain-phase plot in Fig.3 and Fig. 4, respectively. In Fig. 3, the transfer function of 3-pole, 2-zero type and the corner frequencies are as follows:

$$\frac{v_c(s)}{v_o(s)}=\frac{(1+sC_1R_2)\{1+sC_3(R_1+R_3)\}}{s(C_1+C_2)R_1(1+sC_3R_3)(1+s\frac{C_1C_2R_2}{C_1+C_2})} \quad (1)$$

$$f_{z1}=\frac{1}{2\pi C_1R_2}=9.74kHz \quad (2)$$

$$f_{z2}=\frac{1}{2\pi C_3R_1}=7.2kHz \quad (3)$$

$$f_{p1}=\frac{1}{2\pi C_3R_3}=33.86MHz \quad (4)$$

$$f_{p2}=\frac{1}{2\pi C_2R_2}=1.8MHz \quad (5)$$

$$A_{V1}=\frac{R_2}{R_1}=0.914 \quad (6)$$

$$A_{V2}=\frac{R_2(R_1+R_3)}{R_1R_3}\cong\frac{R_2}{R_3}=4300 \quad (7)$$

Fig. 5 shows the frequency characteristics of error amplifier using MATLAB. The natural resonant frequency of the output filter is as follows:

$$f_o=\frac{1}{2\pi\sqrt{LC}}=6.93kHz \quad (8)$$

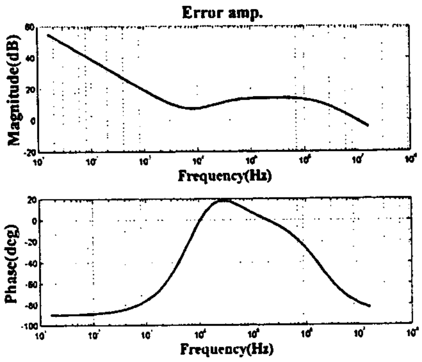


Fig. 5 The frequency characteristics of error amplifier using MATLAB

Table 3 The measurement results for 1-pole, 1-zero

$V_i(V)$	$I_o(A)$	fc (kHz)	phase margin	Gain margin
38	1	7.84	90 deg	14 dB
	5	10.87	46 deg	9.7dB (when -151°)
	6.2	0.29	100 deg	8dB (when -83°)
48	1	11.95	93 deg	13 dB
	5	11.4	74 deg	16 dB
	9.5	16.26	88 deg	12dB (when -126°)
58	1	59.82	80 deg	20.35 dB
	5	12.83	75 deg	23 dB
	11.5	14.79	58 deg	34 dB

3. Experimental considerations

The experimental measurement recorded the loop gain for evaluating the stability when the inputs are $38V$, $48V$ and $58V$ according to the load current variations. Table 3 shows the measured results of the error amplifier compensated as 1-pole, 1-zero type. The measured results of the error amplifier compensated as 3-pole, 2-zero type are listed in table 4. The measured gain/phase graphs are shown from Fig. 6 to Fig. 17.

According to the measured results, as you can see that the f_c cross over frequency are decreased as the load current increase. In the phase margin for expressing the relative stability, the 3-pole, 2-zero compensator is well operated more than the 1-pole, 1-zero compensator in stable region. The phase margin increases as the load current are increased. As shown in Fig. 9, Fig. 13 and Fig. 17, it has stable phase margin when the load is 7A. Also, we can see that the gain margin increases as the load current are increased.

Table 4 The measurement results for 3-pole, 2-zero

$V_i(V)$	$I_o(A)$	f_c (kHz)	Phase margin (dB)	Gain margin (dB)	figure
38	1	70.59	0	0.9275	6
	3	20.05	65.42	19.54	7
	5	20.05	64.28	21.33	8
	6	14.92	60.09	24.26	9
48	1	64.31	18.68	2.59	10
	3	43.61	57.84	11.38	11
	5	34.01	60.16	12.75	12
	7	29.12	73.56	15.33	13
58	1	68.43	12.94	2.21	14
	3	60.43	25.25	5.04	15
	5	51.74	35.25	6.92	16
	7	41.62	50.2	11.19	17

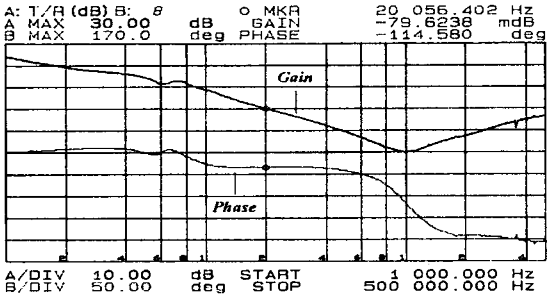


Fig. 6 V_i=38V, I_o=1A

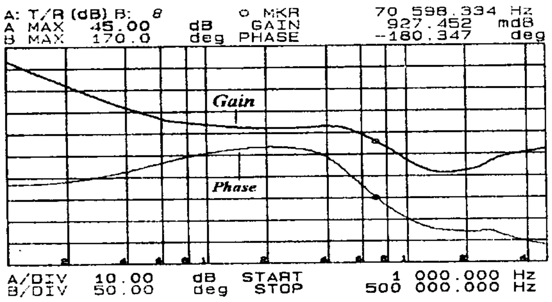


Fig. 7 V_i=38V, I_o=3A

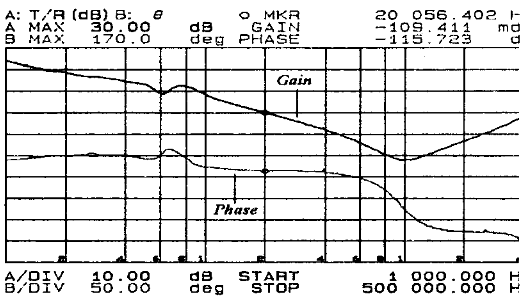


Fig. 8 V_i=38V, I_o=5A

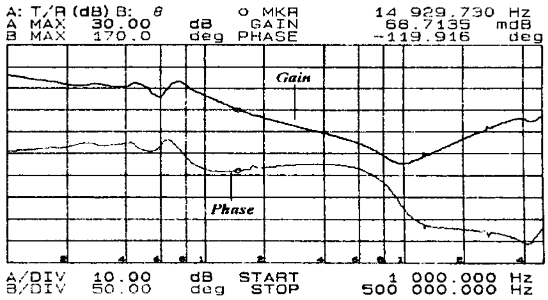


Fig. 9 V_i=38V, I_o=6A

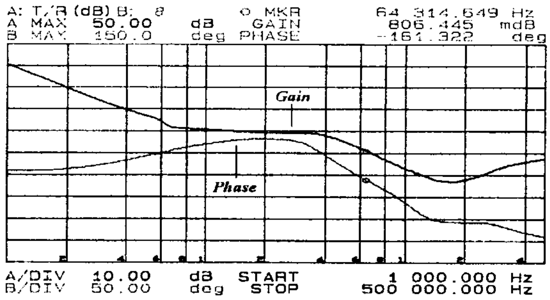


Fig. 10 V_i=48V, I_o=1A

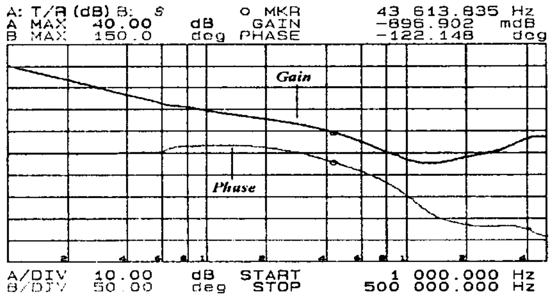


Fig. 11 V_i=48V, I_o=3A

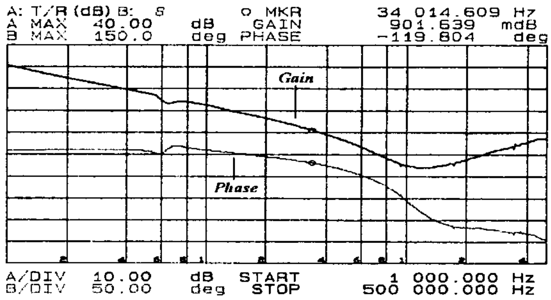


Fig. 12 V_i=48V, I_o=5A

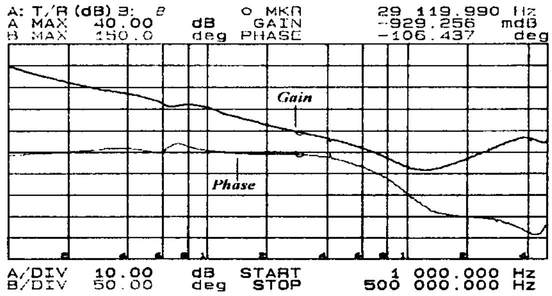


Fig. 13 V_i=48V, I_o=7A

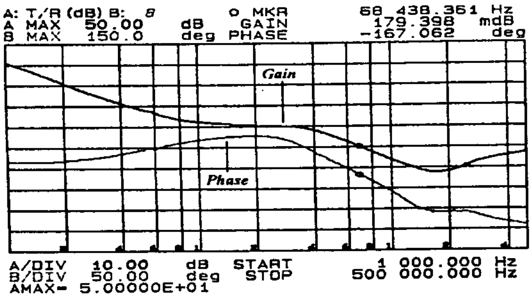


Fig. 14 V_i=58V, I_o=1A

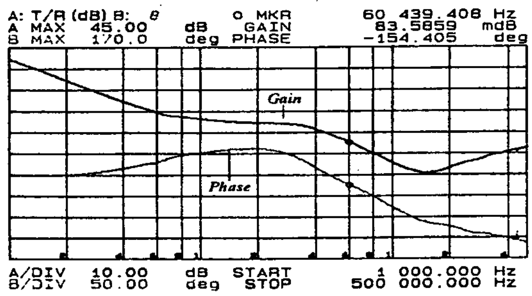


Fig. 15 V_i=58V, I_o=3A

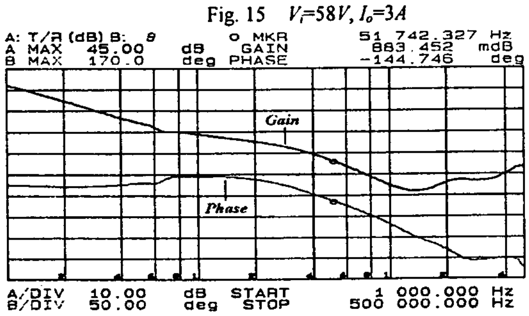


Fig. 16 V_i=58V, I_o=5A

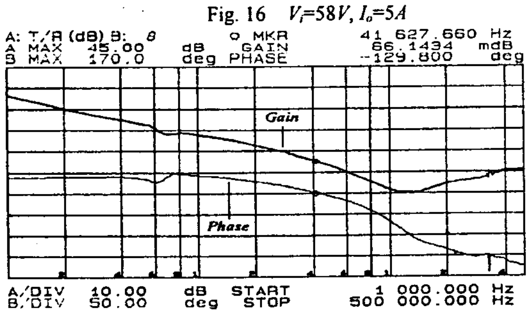


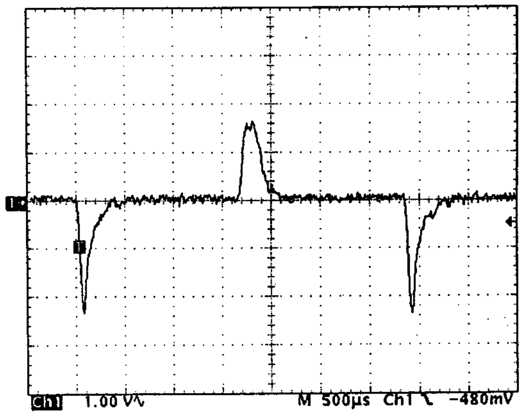
Fig. 17 V_i=58V, I_o=7A

3. Transient response

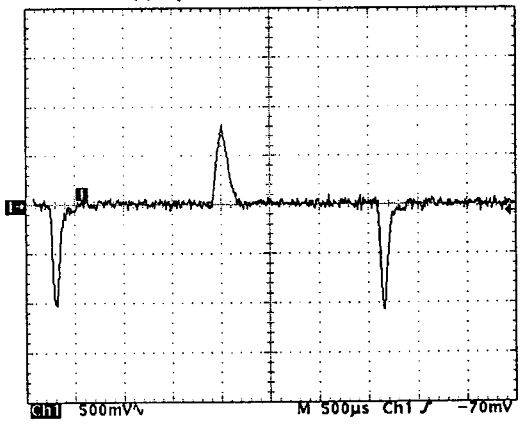
Fig. 18, Fig. 19 and Fig. 20 show the transient responses as the load current is varied from 20% to 80%. All figure (a) are 1-pole, 1-zero type, all figure (b) are 3-pole, 2-zero type. They are measured at each input voltage of 38V, 48V and 58V.

4. Conclusions

The stability for the AT forward MRC is considered experimentally. On the basis of the results of the 1-pole, 2-zero compensated error amplifier, it is improved to the 3-pole, 2-zero compensated error amplifier. Using HP4194A measuring technique, the gain/phase graph is obtained. As a results of measuring the gain margin and the phase margin, we can see that the relative stability is formed in more stable range.

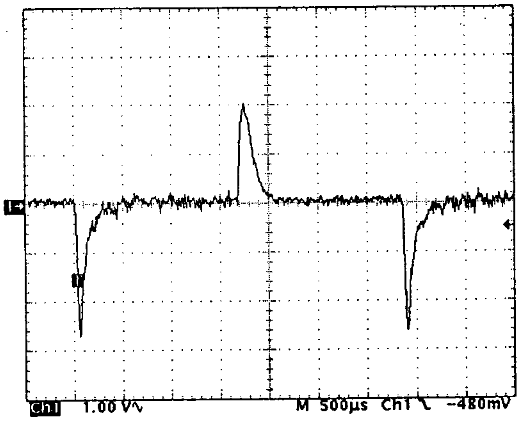


(a) 1-pole, 1-zero compensator

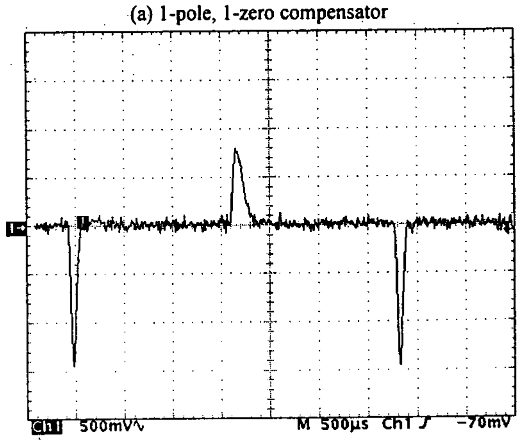


(b) 3-pole, 2-zero compensator

Fig. 18 Input 38V(1.2A~4.8A)

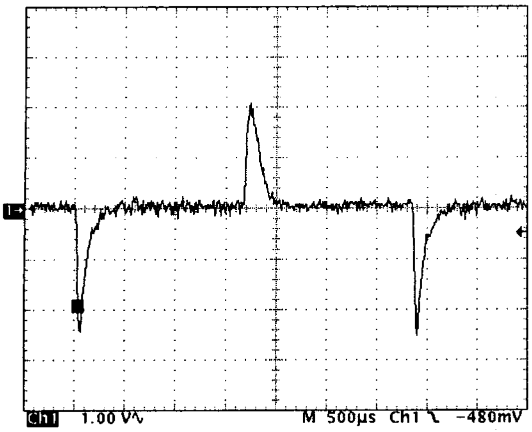


(a) 1-pole, 1-zero compensator

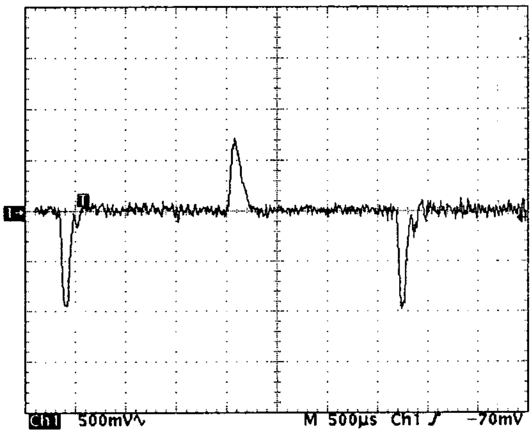


(b) 3-pole, 2-zero compensator

Fig. 19 Input 48V(1.9A~7.6A)



(a) 1-pole, 1-zero compensator



(b) 3-pole, 2-zero compensator

Fig. 20 Input 58V(2A~8A)

References

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