Op-Amp. Integrators with Infinite Q-Factor

Integrierender Operationsverstärker mit unendlichem Gütefaktor

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Abstract:

Two equivalent op-amp inverting integrators having infinite Q-factor are given. One of them is recently published and the other is new. These integrators are obtained using "passive" compensation techniques in a simple manner by adding only a single passive component which is either a resistor or a capacitor. A concept of "active-passive" compensation for the finite op-amp unity gain bandwidth is introduced. This concept is applied to obtain a noninverting integrator with infinite Q-factor.

Übersicht:

Es werden je ein bereits bekannter und ein neuer integrierender und invertierender Operationsverstärker unendlicher Güte miteinander verglichen. Beide Integratoren arbeiten in einfacher Weise mit „passiver" Kompensationstechnik unter Hinzufügung eines einzigen passiven Bauelementes, welches entweder ein Widerstand oder eine Kapazität sein kann. Es wird ein Vorschlag für eine „aktiv-passive" Kompensation für das endliche Verstärkungs-Bandbreitenprodukt des Operationsverstärkers gemacht. Dadurch erhält man einen nichtinvertierenden Integrator mit unendlichem Gütefaktor.

Für die Dokumentation:

Operationsverstärker / Integrator / Gütefaktor / Filter

1. Introduction

The op-amp integrators find wide use in many applications in particular in certain types of active-RC filters [1—4]. The finite and complex gain nature of the used op-amps degrades significantly the performance of these active filters. Therefore, many authors have proposed means to improve the performance of the op-amp integrator (inverting and noninverting) when looked upon as an active building block [5—7].

In fact, there are two main compensation methods for the effect of the finite gain-bandwidth of op-amps namely: "passive compensation" and "active compensation".

The "passive compensation" method depends upon some additional passive components [5] to match the op-amp finite unity gain-bandwidth according to some design constraints. On the other hand, "active compensation" one depends upon the matching properties of op-amps whereby op-amps in a circuit provide compensation for other op-amps in the same circuit.

Regarding the op-amp integrators, the concept of the integrator Q-factor introduced in [1] will extensively be used here. The ideal op-amp integrator must have an infinite Q-factor. It will be shown that the compensated integrator of Brackett and Sedra [6] is the equivalent active compensated integrator to Wilson's [5] passive compensated one. Moreover, two equivalent passive compensated integrators having an infinite Q-factor are given. One of them has already been reported by Allen and Parrish [7].

On the other hand, a concept of "active-passive" compensation is introduced and applied to obtain a noninverting integrator with infinite Q-factor.

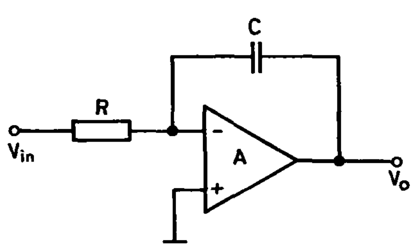

Fig. 1: Miller inverting integrator

2. The op-amp. integrator Q-factor

Fig. 1 shows the familiar Miller (inverting) integrator. With ideal op-amp, the voltage transfer function is

$$\frac{V_0}{V_{in}} = -\frac{1}{sCR} = -\frac{\omega_0}{s}, \quad (1)$$

where

$$\omega_0 = \frac{1}{CR}.$$

If the op-amp is compensated to have a single-pole open-loop response with a unity gain bandwidth ω_t, then its gain is approximately given by

$$A(s) = \frac{\omega_t}{s}. \quad (2)$$

The voltage transfer function of the circuit of Fig. 1 becomes

$$\frac{V_0}{V_{in}} = -\frac{1}{sCR}\varepsilon(s), \quad (3)$$

where

$$\varepsilon(s) = \frac{1}{1+\frac{\omega_0}{\omega_t}+\frac{s}{\omega_t}} = \frac{1}{1+\frac{s}{\omega_t}}; \quad \frac{\omega_0}{\omega_t} \ll 1.$$

$\varepsilon(s)$ is the error function contributed by the finite unity gain bandwidth of the imperfect op-amp.

The concept of the integrator Q-factor introduced in [1] will be used here. So, if the op-amp frequency response is taken into account, the transfer function of an integrator circuit may be expressed as

$$T(\mathrm{j}\,\omega) = \frac{1}{R(\omega) + \mathrm{j}\,X(\omega)}, \tag{4}$$

where $R(\omega)$ and $X(\omega)$ are real functions of the frequency variable ω. In the ideal case $R(\omega)$ is zero. The integrator Q-factor is defined by analogy to the Q-factor of a passive reactive element as

$$Q_\mathrm{I} = \frac{X(\omega)}{R(\omega)}. \tag{5}$$

Using equations (3), (4), and (5) it has been shown [6] that the Q-factor of the Miller integrator is

$$Q_\mathrm{I} \simeq -|A(\mathrm{j}\,\omega)| = -\frac{\omega_\mathrm{t}}{\omega}; \quad \frac{\omega}{\omega_\mathrm{t}} \ll 1. \tag{6}$$

3. Wilson and Brackett and Sedra compensated integrators

Fig. 2 shows two compensated schemes for Miller integrator. In Fig. 2 a "passive" compensation technique has been used by Wilson [5] in which a simple first-order high pass positive feedback, with $C_0\,R$ selected as $1/\omega_\mathrm{t}$, is used giving the following transfer function

$$\frac{V_0}{V_\mathrm{in}} \simeq -\frac{1}{s\,C\,R}\,\frac{1+\dfrac{s}{\omega_\mathrm{t}}}{1+\dfrac{s}{\omega_\mathrm{t}}+\dfrac{s^2}{\omega_\mathrm{t}^2}}; \quad \frac{\omega_0}{\omega_\mathrm{t}} \ll 1. \tag{7}$$

The Q-factor, derived here, is found to be

$$Q_\mathrm{I} \simeq -|A(\mathrm{j}\,\omega)|^3 = -\frac{\omega_\mathrm{t}^3}{\omega^3}; \quad \frac{\omega}{\omega_\mathrm{t}} \ll 1. \tag{8}$$

In Fig. 2 b "active" compensation technique has been used by Brackett and Sedra [6] in which a voltage follower in the feedback path is used. It is required for compensation that the op-amps used (A_1 and A_2) must have identical unity gain bandwidths ω_t.

It is found that the compensated integrator of Fig. 2 b is the equivalent active compensated integrator to Wilson's passive compensated one of Fig. 2 a, i. e., it has the same voltage transfer function and Q-factor obtained above for Wilson's scheme.

4. Two equivalent "passive" compensated inverting integrators

Fig. 3 shows two compensated schemes for Miller integrator in which "passive" compensation techniques are used.

In Fig. 3 a C_0 is selected according to the following design equation

$$C_0\,R = \frac{1}{\omega_\mathrm{t}}. \tag{9}$$

The above equation yields the following voltage transfer function

$$\frac{V_0}{V_\mathrm{in}} = -\frac{1}{s\,C\,R}\,\frac{1+\dfrac{s}{\omega_\mathrm{t}}}{1+\dfrac{\omega_0}{\omega_\mathrm{t}}+\dfrac{s}{\omega_\mathrm{t}}\left(1+\dfrac{\omega_0}{\omega_\mathrm{t}}\right)}, \tag{10}$$

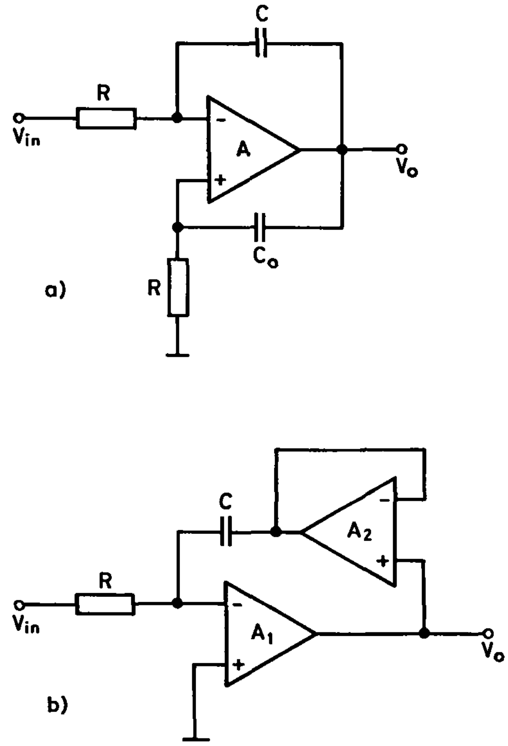

Fig. 2: "Passive" compensated Miller integrator of Wilson (a) and "Active" compensated Miller integrator of Brackett and Sedra (b)

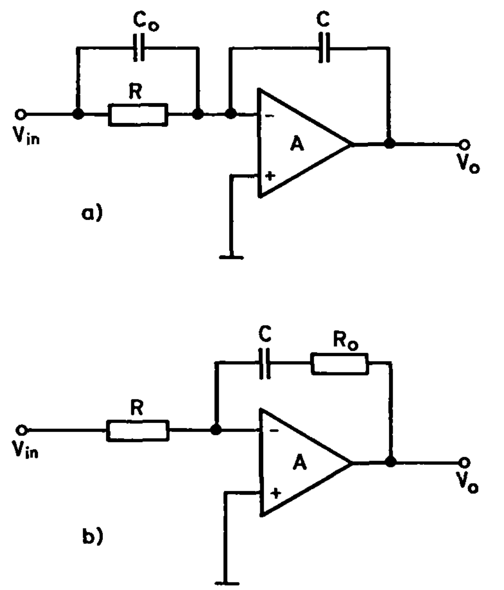

Fig. 3: A new passive compensated Miller integrator with infinite Q-factor (a) and Allen and Parrish compensated integrator (b) [7]

which can be written in the form

$$\frac{V_0}{V_\mathrm{in}} = -\frac{1}{s\,C\,R\left(1+\dfrac{\omega_0}{\omega_\mathrm{t}}\right)}. \tag{11}$$

So, with $s = \mathrm{j}\,\omega$, if (11) is written in the form of (4) it will be clear that $R(\omega)$ is equal to zero; i. e., the integrator Q-factor takes the value of infinity. This is equivalent to have an ideal integrator.

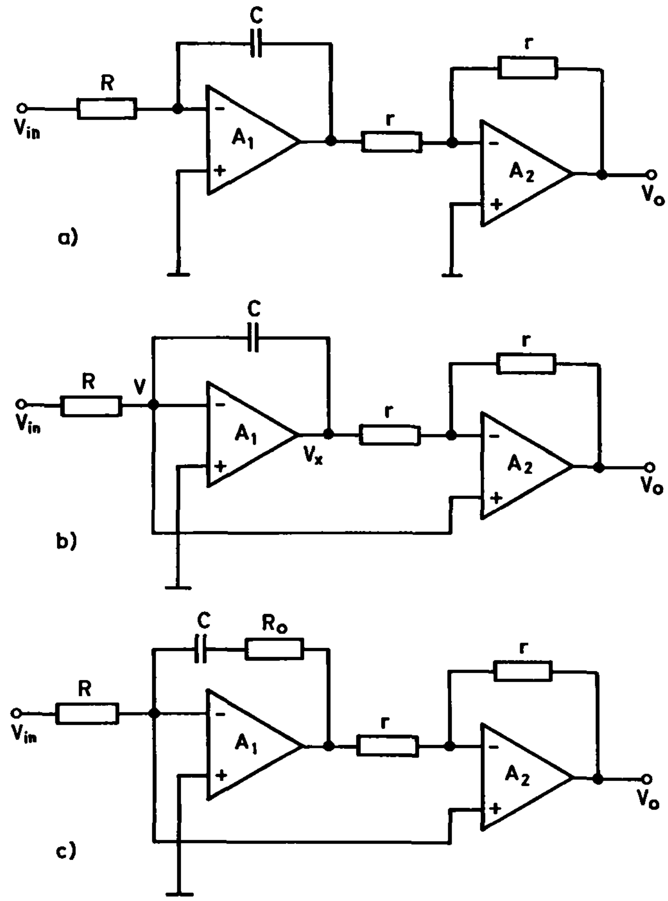

Fig. 4: Miller-inverter cascade (noninverting) integrator (a), the modified Miller-inverter cascade (noninverting) integrator of Brackett and Sedra (b) and new noninverting integrator with infinite Q (c)

Also in Fig. 3 b, if R_0 is selected according to the following design equation

$$R_0\,C = \frac{1}{\omega_t}. \tag{12}$$

Then, the voltage transfer function of (11) will be obtained again for the compensated integrator circuit of Fig. 3 b.

So, the addition of a parallel capacitor (to the input resistor R) or a series resistor (to the feedback capacitor C) according to some design constraints [(9) and (12)] will result in a negative real zero which is very near to the negative real pole contributed by the imperfect amplifier. In other words if the condition of $\omega_0/\omega_t \ll 1$ is considered (the same condition by which (7) is derived). Then (11) will become

$$\frac{V_0}{V_{in}} \simeq -\frac{1}{s\,C\,R}; \quad \frac{\omega_0}{\omega_t} \ll 1, \tag{13}$$

which has the form of (1) obtained for the case of having ideal op-amp. Therefore, these compensated integrators are better than that of Fig. 2. However, the main disadvantages of these compensation schemes are generally that of the "passive" compensation technique. It is well known that the op-amp unity gain bandwidth is sensitive to variations in ambient temperature or power supply voltage. So, if these conditions are changed the compensation will no longer be satisfactory.

On the other hand, the addition of a capacitor (Fig. 3 a) changes the nature of the integrator input impedance. This is not the case in Fig. 3 b in which the input impedance remains unchanged.

5. An "active-passive" compensated noninverting integrator

Fig. 4 a presents the most obvious way of realizing a noninverting integrator namely, by a Miller-inverter cascade.

The Q-factor of this integrator, derived in [6], is

$$Q_I \simeq -\frac{1}{3}\,|A(\mathrm{j}\,\omega)| = -\frac{1}{3}\frac{\omega_t}{\omega}; \quad \frac{\omega}{\omega_t} \ll 1. \tag{14}$$

Brackett and Sedra [6] showed that if the summing junction potential of A_1 is fed to the noninverting input of A_2, as shown in Fig. 4 b, this will yield the following inverter transfer function

$$\frac{V_0}{V_x} = -\left(\frac{1+\dfrac{2}{A_1}}{1+\dfrac{2}{A_2}}\right) \tag{15}$$

which for matched amplifiers (available in a dual package), becomes $V_0/V_x = -1$ and the inverting input terminal of A_2 becomes a true virtual ground.

The Q-factor of the integrator of Fig. 4 b, derived in [6], is

$$Q_I \simeq -|A(\mathrm{j}\,\omega)| = -\frac{\omega_t}{\omega}; \quad \frac{\omega}{\omega_t} \ll 1, \tag{16}$$

which is the same value obtained for the uncompensated Miller integrator of Fig. 1. This means that the integrator circuit of Fig. 4 b contains only one imperfect amplifier A_1 (since A_2 behaves as an ideal amplifier).

However, the addition of resistor R_0, as shown in Fig. 4 c, such that

$$R_0\,C = \frac{1}{\omega_{t_1}} = \frac{1}{\omega_{t_2}} \tag{17}$$

will result in a noninverting integrator with infinite Q-factor. Here, "active" compensation technique is used with A_2 and, "passive" compensation one is used with A_1. So, the new concept of "active-passive" compensation is used to obtain an ideal noninverting integrator with real op-amps (Fig. 4 c).

It is of importance to note that for the "active" compensated noninverting integrator of Fig. 4 b, if Wilson's passive compensation (Fig. 2 a) is used with A_1, this will affect the "active" compensation used with A_2. This is because the relationship between V_2^- (the inverting input voltage of A_2) and V_1^+ (the noninverting input voltage of A_1) is found to be

$$V_2^- = V_1^+\frac{A_1}{2+A_2} - V\frac{A_1-A_2}{2+A_2}. \tag{18}$$

Hence V_1^+ should be zero otherwise the inverting input terminal of A_2 loses its property of becoming a true virtual ground (when $A_1 = A_2$). Wilson's compensation however, if used with A_1 will result in a nonzero value of V_1^+.

6. Acknowledgement

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Tagungen

17. 9.—20. 9. 1979	**European Microwave Conference and Microwave Exhibition; Brighton, East Sussex, England** (Microwave Exhibitions and Publishers Ltd., Temple House, 36 High Street, Sevenenoaks, Kent TN 13 1 JG)
18. 9.—20. 9. 1979	**ESSCIRC '79 (5th European Solid State Circuits Conference); Southampton, England** (VDE-Zentralstelle Tagungen, Stresemannallee 21, 6000 Frankfurt/M. 70)
9. 10.—12. 10. 1979	**NTG-Fachtagung „Text- und Bildkommunikation"; Stuttgart** (VDE-Zentralstelle Tagungen, Stresemannallee 21, 6000 Frankfurt/M. 70)
18. 10.—20. 10. 1979	**INTERNEPCON UK und Internationale Mikrowellenausstellung; Brighton, East Sussex, England** (Kiver Communications Ltd., Millbank House, 171—185 Ewell Road, Surbiton, Surrey KT6 6 AX)
24. 10.—26. 10. 1979	**Fachtagung „Feinwerktechnik bei elektronischen Systemen"; Bad Nauheim** (VDI/VDE-Gesellschaft Feinwerktechnik, Graf-Recke-Str. 94, 4000 Düsseldorf 1)
20. 11.—23. 11. 1979	**Electronics '79 (Electronic Components Industry Fair); Olympia, London** (Industrial and Trade Fairs Ltd., Radcliffe House, Blenheim Court, Solihull, West Midlands B91 2BG)
10. 12.—15. 12. 1979	**ELEC 79 (Internationale Fachausstellung der Elektro-Ausrüstung); Paris** (Service des Presse, 20. rue Hamelin, F 75116 Paris)

Optical Communication Conference Amsterdam 1979

The Optical Communication Conference Amsterdam 1979, association of the fifth European Conference on Optical Communication and Second International Conference on Integrated Optics and Optical Communication will be held in Amsterdam (Netherlands), September 17—19, 1979.

Location: RAI Conference Buildings, Amsterdam, Netherlands.

Information Contact: J. H. C. van Heuven, Secretary, Philips Research Labs, Eindhoven, Netherlands. Tel. 0 40—74 31 93.

VDE-Kongreß '78 in Hannover

Die 60. Hauptversammlung des Verbandes Deutscher Elektrotechniker fand vom 2. bis 5. Oktober 1978 in Hannover statt und stand unter dem Motto „Revolutioniert die Elektrotechnik unsere Welt?"

Antworten auf diese Frage wurden in den Übersichtsvorträgen der einzelnen Fachrichtungen innerhalb der Elektrotechnik untersucht. Wichtiger jedoch als die Beantwortung der Frage schienen dem Vorsitzenden des VDE, Dr.-Ing. E. h. Dipl.-Ing. Günther Niehage, Dortmund, das Nachdenken um die Diskussion über die Folgen des technischen Fortschritts für unsere Lebensumstände und das ständige Gespräch mit der Gesellschaft, in der wir leben und der sich die Ingenieure in ihrem Schaffen verpflichtet fühlen. In der Eröffnungsansprache zur Festversammlung des VDE-Kongresses ließ Niehage anklingen, wie notwendig dieses Gespräch sei; die Verständigungsschwierigkeiten und Mißverständnisse bei der Auseinandersetzung über die Kernenergiefrage und die Probleme, die die Computertechnologie mit sich bringt, nannte Niehage als Beispiele.

Im Zusammenhang mit der Nachrichtentechnischen Gesellschaft im VDE (NTG), die unter anderem das Gebiet der Mikroelektronik behandelt, kam Niehage auch auf das Problem der Informationsfülle, mit dem alle wissenschaftlichen Disziplinen zu kämpfen hätten. 1972 habe man deshalb schon mit anderen Trägern die Zentralstelle Dokumentation beim VDE (ZDE) gegründet, die systematisch die gesamte Fachpresse auswerte und dokumentiere. Zwischenzeitlich sei die ZDE als eine Abteilung in das Fachinformationszentrum Technik (FIZ) eingebracht worden.

In seinem Tätigkeitsbericht teilte der Generalsekretär des VDE, Professor Dr. Dietrich, mit, daß die Mitgliederzahl die 30 000-Grenze erreicht habe. Den Zuwachs um mehr als acht Prozent von 27 350 Mitgliedern im Oktober 1976 und den Zuwachs der Jungmitglieder um gar 46 Prozent von 4 007 auf rund 6 000 Mitglieder wertete er als Ergebnis einer zielstrebigen Arbeit.

Auch zu der Umstrukturierung des Zeitschriftenkonzepts des VDE-Verlages Berlin—Offenbach nahm der Generalsekretär Stellung. etz-a und etz-b werden künftig zweimal monatlich als etz (Elektrotechnische Zeitschrift) als Organ des VDE und der Energietechnischen Gesellschaft im VDE erscheinen. Wissenschaftliche Arbeiten und solche Aufsätze, die der Darstellung sehr spezieller Einzelprobleme gewidmet seien, werden künftig in der (neuen) Zeitschrift etz-Archiv (Archiv für elektrische Energietechnik) veröffentlicht. Für die Ingenieure der Disziplin Nachrichtentechnik erscheint weiterhin die Nachrichtentechnische Zeitschrift (ntz) mit Übersichtsaufsätzen, Einzelinformationen und Kommentaren. Hinzu kommt auch in diesem Bereich ein Archiv (ntz-Archiv/Archiv für Nachrichtentechnik).

„Wenn wir unsere wirtschaftlichen Ziele erreichen und gleichzeitig unsere Versorgungssituation verbessern wollen, müssen wir in Europa eine energische und vorausschauende Energiepolitik betreiben!" Dies erklärte in einem Festvortrag Dr. Guido Brunner, Brüssel, Mitglied der Kommission der Europäischen Gemeinschaften. Die Europäische Gemeinschaft habe, nicht nur im Hinblick auf die künftig wachsende Energienachfrage, Maßnahmen bereits eingeleitet. In Ansätzen gäbe es auch eine gemeinsame Energiepolitik. Als Beispiele nannte Brunner die Aktionen zur rationellen Energienutzung und Einsparung von Energie, die Mobilisierung von Gemeinschaftsmitteln zur Förderung von Energieinvestitionen oder für die Energieforschung.