Int. J. Electron. Commun. (AEÜ) 68 (2014) 595–601

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

Oscillation based test method of parameterization of open loop op amp and its authentication

Bijay K. Sharma *

Electronics and Communication Engineering Department, National Institute of Technology, AshokRajpath, Patna 800005, Bihar, India

ARTICLE INFO

Article history:
Received 6 February 2013
Received in revised form 8 January 2014
Accepted 10 January 2014

Keywords:
Barkhausen criteria
Dominant poles
Frequency-domain
Slew rate
Full power band-width

ABSTRACT

The analytical design of differential amplifiers, the building blocks of an op-amp, requires an elegant, handy and computationally simple experimental method of measuring the d.c.super-gain of these blocks. This paper presents such an oscillation based test (OBT) by putting the Op.Amp. under test in the close loop of state variable filter. The oscillation frequency of the linearized system directly yields the d.c. open loop gain, the dominant pole and the second order non-dominant pole of test Op.Amp. The d.c. open loop gain of DUT is further authenticated by a novel method of frequency domain analysis using a super attenuator. The authentication is positive with 95 percent confidence level (ε, 0 percent, 9.64 percent) thereby establishing the validity of OBT method.

1. Introduction

In 1981 the author had proposed a universal hybrid-π model as a more accurate small signal model of CE BJT [15,18]. The model was subsequently used for predicting the output impedance and the sustaining voltage of different configurations of current sources. Calculated results obtained from the universal model conform to the experimental results [16] as well as to the simulated results. In the second phase of testing the accuracy of the universal model, it was used for theoretically analyzing the d.c. gain of a super gain amplifier and verifying it experimentally [17]. In this context the need arose for a set-up for experimentally measuring the unusually large d.c. gain of a super gain amplifier. In frequency domain analysis of the open loop differential amplifier using a current mirror [17], to achieve small signal approximation, the input signal is at tens of microvolt level and, at this level of input signal, the equivalent input noise level becomes comparable. The equivalent input noise level comprises of thermal noise produced by the input resistance, the noise figure of the active devices (BJT in this case) and EMI due to the surrounding 50 Hz power fields. This equivalent noise level affects the input signal and hence the output leading to inaccurate measurements. This problem was faced in the last experiment [17] even though the experimental results had well conformed to the theoretical results as obtained from the Universal hybrid pi model but the problem would get aggravated as the gain becomes higher than 1000. The static method of finding the d.c. gain of the op-amp is as susceptible to inaccuracy [9]. This involves a difference of two nearly equal voltages hence this is tedious, cumbersome and inaccurate with a large margin of error. Over the years several methods have been developed for measuring the open loop parameters of an op-amp [1,4–6,10,12,14]. Sansen et al. [14] and Higuchi et al. [6] obtain the open loop parameters but fall short of the requirement of being handy and computationally simple. The methods suggested by Awad [1], by Natarajan [10] and by Porta et al. [12] are unable to arrive at the open loop DC gain parameter explicitly. They measure the Gain Bandwidth Product (GBP) which is the location of the second order Pole (Appendix A) [9]. The method described by Grieken et al. [4] are automatic characterization using network analyzers but are sensitive to the circuit layout and the parasitics introduced in the process. The method described by Giustolisi et al. [5] is also concerned with stability studies only. The latest work by Pintelon et al. [11] faces the dual problem of full-power bandwidth violation for μA741 Op.Amp. which has a low slew rate of 0.5 V/μs while measuring the unity-gain BW at near MHz frequency range and equivalent input noise level swamping the input signal while measuring the d.c. open loop gain at very low frequencies. Since Pintelon et al. method cannot be adopted as the benchmark for μA741 Op.Amp. so this method has been kept out of the per view of this paper. There was an urgent need of the time to develop an elegant method of parameterization of the super-gain amplifier and which would simultaneously be handy and computationally simple. A super attenuator set up for frequency domain analysis is used in this paper along the lines of Graeme et al. Set Up. [3]. By this method the DC Gain and upper −3 dB frequency (the

* Tel.: +91 9334202848; fax: +91 6122670631.
E-mail addresses: bijaymahanthmaniari@gmail.com, electronics@nitp.ac.in

1434-8411/$ – see front matter © 2014 Elsevier GmbH. All rights reserved.
http://dx.doi.org/10.1016/j.aeue.2014.01.007

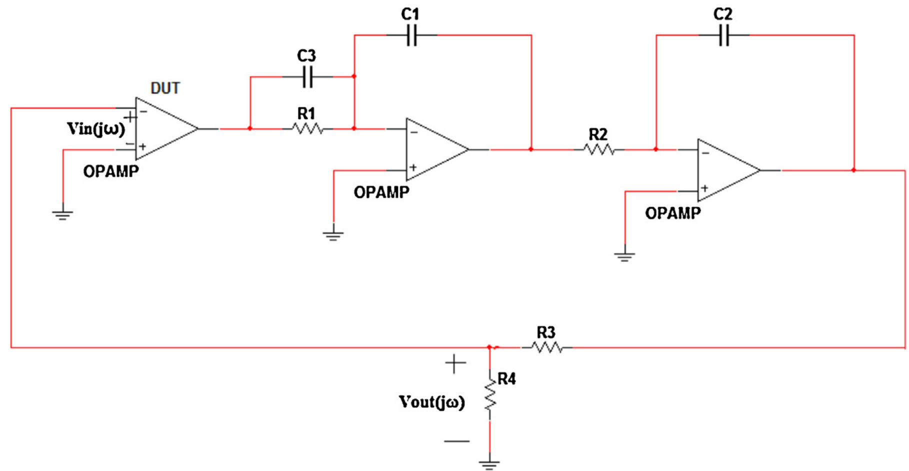

Fig. 1. Modified State Variable filter with the dominant pole of open loop Op.Amp.μA741 compensated by a zero of the following stage.

dominant pole) of the open loop op amp. are directly deduced and used as the bench mark for validation. A new alternative, oscillation based test (OBT), is developed in this paper which is elegant, handy, accurate and simple. Here the test op-amp, device under test (DUT), is used in open loop configuration in the first stage of state variable filter as shown in Fig. 1. If DUT was wide-band amplifier then the classical quadrature oscillator would suffice for OBT. In our case μA741 is used as the first stage and hence the state variable filter does not remain a linear system because of the nominal dominant pole of the Op.Amp.at 10 Hz. The Transfer function of the classical quadrature oscillator is given by (1).

$$H(j\omega) = \frac{V_{out}(j\omega)}{V_{in}(j\omega)} = \frac{A_{VO}}{(1 + j\omega/\omega_p)} \times \frac{R_4}{R_1 R_2 C_1 C_2 (R_3 + R_4)} \times \frac{1}{\omega^2} \quad (1)$$

The transfer function represented by (1) is the ratio of voltage at the output port of the $(R_3 - R_4)$ L-network and Voltage at the input port of test Op.Amp. as indicated in Fig. 1. To linearize the classical quadrature oscillator, a zero ($\omega_{zero} = 1/[R_1 C_3]$) is introduced in this filter as shown in Fig. 1 to compensate for the dominant pole ω_p of the test Op.Amp. and make the system linear. To adjust the loop gain we have introduced a resistive attenuator in the global feedback loop (R3, R4). The transfer function of this modified quadrature oscillator along the closed loop gain path is given by (2).

$$H(j\omega) = \frac{A_{VO}}{(1 + j\omega/\omega_p)} \times \frac{R_4}{R_1 R_2 C_1 C_2 (R_3 + R_4)} \times \frac{1}{\omega^2} \times [1 + j\omega R_1 C_3] \quad (2)$$

When the introduced zero exactly compensates the dominant pole then at the oscillatory frequency $V_{out}(j\omega)$ is identical to $V_{in}(j\omega)$ and Barkhausen Criteria of Unity Loop Gain in magnitude and Zero Phase is fulfilled and the frequency of oscillation is given by (3).

$$\omega_{OSC} = \sqrt{\frac{A_{VO} R_4}{R_1 R_2 C_1 C_2 (R_3 + R_4)}} \quad (3)$$

Here A_{VO} = D.C. gain and low frequency flat band differential mode gain of the Op.Amp. This expression includes the d.c. open loop gain of the test op-amp. Thus the frequency of oscillation will directly yield the d.c. open loop gain of the test op-amp. The degree of accuracy with which the open loop gain is obtained is constrained only by the accuracy of the measurement of the frequency of oscillation of the OBT set up as well as by the purity of sinusoidal oscillation. The magnitude of the ZERO introduced in the modified State Variable Filter for perfect compensation, indicated by the minimization of the harmonic distortion, will yield the dominant pole of the test Op.Amp. OBT is becoming a popular and handy method for quality control in Analog Circuit and Mixed Signal Circuit manufacturing [7], [13]. In recent years it has been utilized for CMOS op-amp parameterization also [19].

2. Theoretical analysis of the state variable filter

Fig. 1 gives the actual OBT set-up used in this paper for parameterizatiion of the Op.Amp. In the figure, the first stage is the test op-amp (device under test – DUT) in open loop configuration and the second and third stage consists of inverting integrators with a zero introduced in the second stage. The Transfer Function of the modified quadrature oscillator as shown in Fig. 1 is given by (2). The system will be linearized if the introduced zero in Fig. 1 compensates the dominant pole of the test op.amp.i.e.

$$\omega_{zero} = \frac{1}{R_1 C_3} = \omega_p \quad (4)$$

Once perfect compensation is achieved, the frequency of sinusoidal oscillation is obtained by applying the Barkhausen criteria. Therefore the theoretical expression of frequency of oscillation of modified universal state variable filter assuming linear system is given by (3).

There could have been an alternative method of achieving a linear system that is to use a describing function [20] but which is tedious and time consuming.

From frequency of oscillation expression, DC Gain is deduced to be:

$$A_{VO} = (2\pi f_{OSC})^2 \times R_1 R_2 C_1 C_2 \times \frac{R_3 + R_4}{R_4} \quad (5)$$

From (4) and (5), the Gain-Bandwidth Product (GBP) of the given Op.Amp.is deduced as:

$$GBP = 2\pi f_{OSC}^2 \times \frac{C_1 C_2}{C_3} \times (R_3 + R_4) \times \frac{R_2}{R_4} \quad (6)$$

By definition GBP is the Unity Gain BW of the open-loop Op.Amp. In Op.Amp.μA741 the dominant pole zero dB cross-over is placed at −3 dB frequency of the second rollover to ensure a phase margin of 45° in the worst case scenario of negative feed-back which is the voltage follower(Appendix A) [9].

3. The experimental set up and measurement based on oscillation based test for open loop measurement of DUT

The experimental setup used in this investigation is as shown in Fig. 1. The component parameters used in this setup are given in Table 1. The component parameters have been obtained by