Exploring Bandwidth, Gain Margin and Phase Margin in Non-Invasive Measurement

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Summary

Among the most frequently asked questions regarding non-invasive stability measurement are "How do I determine the bandwidth, phase margin and gain margin from the non-invasive measurement". The answer is simple. These terms are all fragments of our imagination, despite the fact that we have come to know and love them. They were created to simplify the process of defining and describing stability by defining three points along the curve. The proper assessment of stability comes down to the proximity of the transfer curve to the singular unstable point at 1,0 (or -1,0 depending on where you include the negative feedback term). There can be one or many points that come close to the singular unstable point, and these may or may not be the phase margin and gain margin.

Keywords

Signal injector, current injector, high speed, POL, PDN, line injector, output impedance, input impedance, bode plot, PSRR, transient response

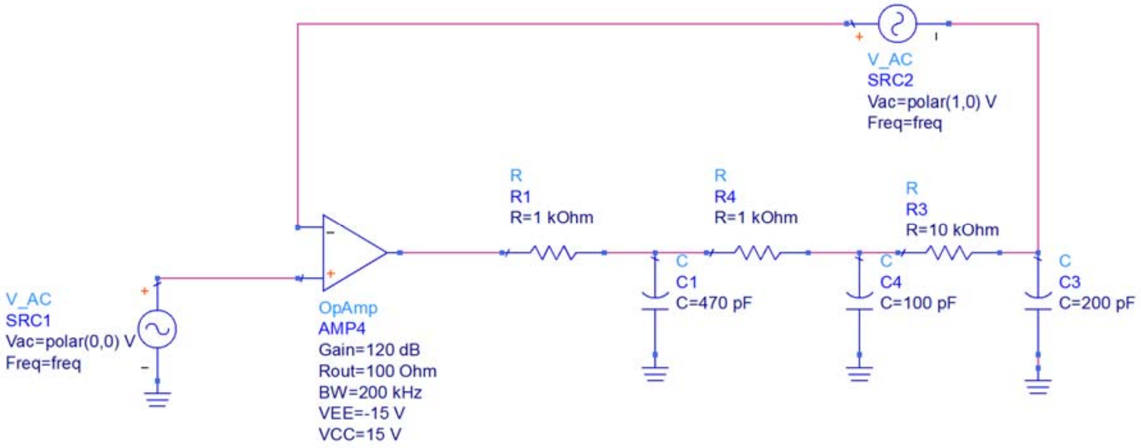
Introduction

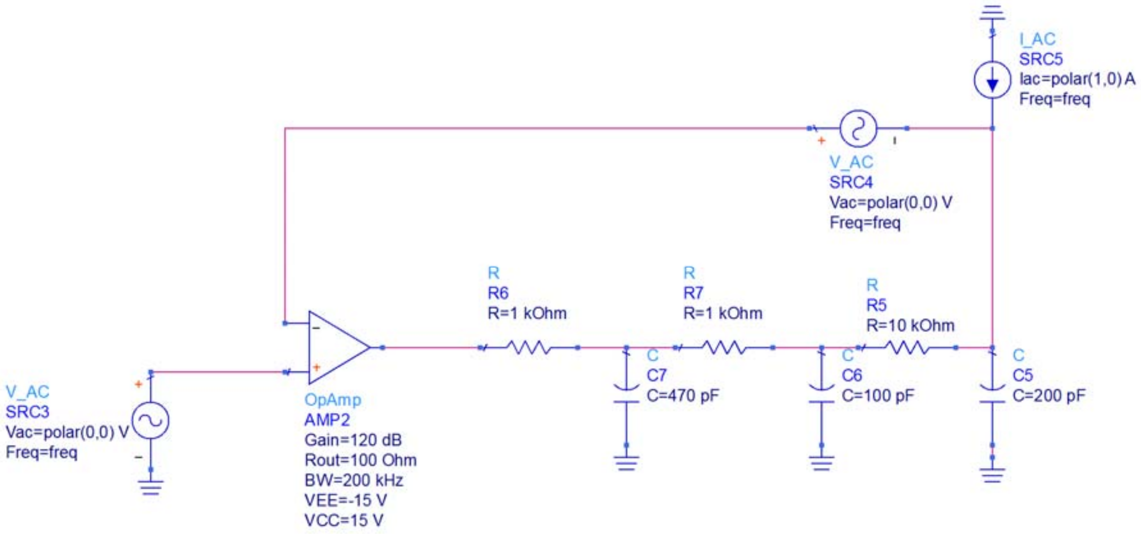
It has become more difficult to assess the stability of linear regulators, voltage references, switching regulators and audio amplifiers as these devices become more integrated, eliminating the circuit access needed for the traditional Bode measurement to evaluate stability. While we have written numerous articles on the subject of non-invasive stability measurement[i] and the limitations of Bode analysis in general[ii], we continue to receive many questions about the specific assessment of bandwidth, phase margin and gain margin from the non-invasive measurement data.

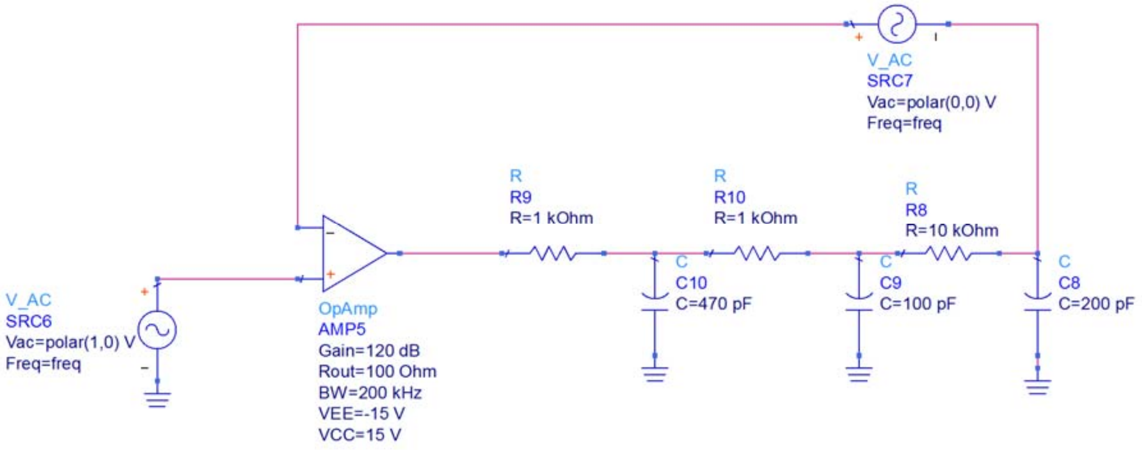
These terms, are related to the Bode plot, and I would argue have little significance in a stability assessment. It is shown in reference ii that it is possible for a control loop to have good phase margin and gain margin results, while at the same time presenting poor stability. Since the control loop is designed to optimize the closed loop circuit performance, this article will look at both open loop and closed loop characteristics.

The first example shows an opamp circuit with three additional resistor capacitor phase shifting terms. The selection of the opamp gain bandwidth and the location of the additional poles are arbitrary, but they serve to demonstrate the overall concepts of stability and why the concepts of gain and phase margin are not specifically of interest.

Three copies of the circuit are created, so that three independent simulations can be performed simultaneously. One circuit is used to show the Bode plot of the open loop circuit, one circuit is used to show the closed loop output impedance and once circuit is used to show the forward closed loop gain. The open loop gain is shown as a traditional Bode plot and also as a polar plot.





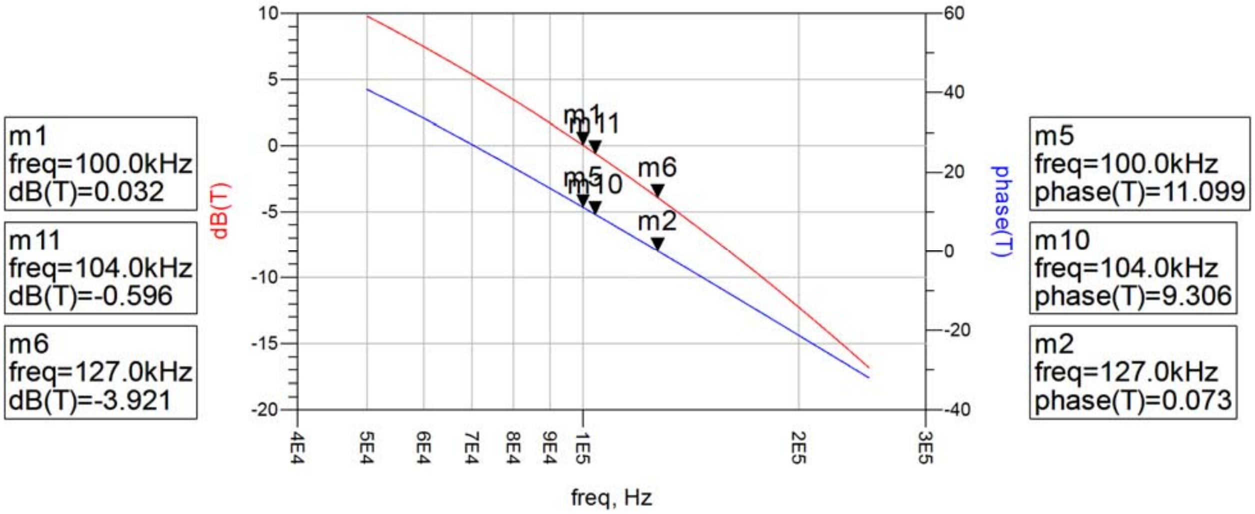


Three copies of a simple opamp circuit are used to allow simultaneous simulation and display of Bode plot forward gain and output impedance. The Bode plot is the traditional assessment, while the forward transfer and output impedance are both non-invasive measurements.

Defining the loop gain T as the output divided by the input

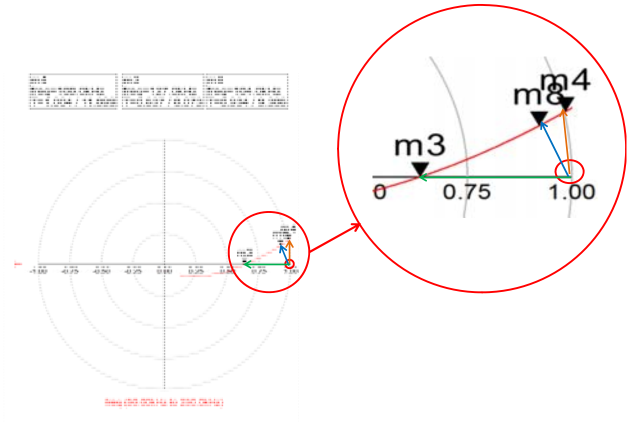
Eqn T=(output/input)

The open loop Bode plot shows three selected points, identified on both the gain and phase traces. The three frequencies selected represent the phase margin, which also reflects the bandwidth, the gain margin and a specifically selected point between the two.



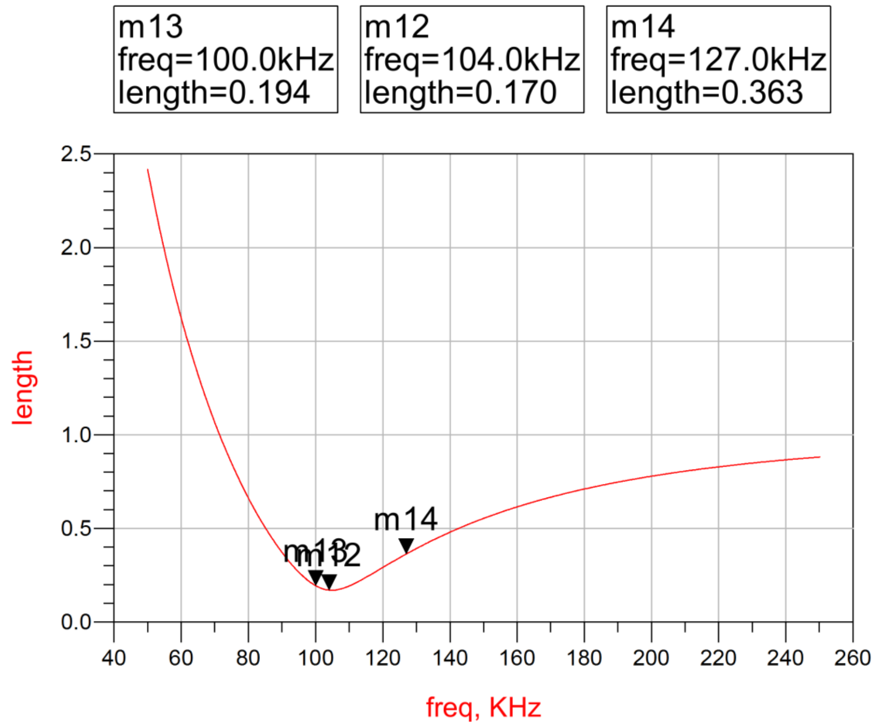
The bandwidth and phase margin are seen as 100kHz and 11.1 Deg while the gain margin is seen at 127kHz and -3.9dB. A selected point between the two indicates -0.6dB and 9.3 Deg at 104kHz.

The same three points can be seen in the polar plot



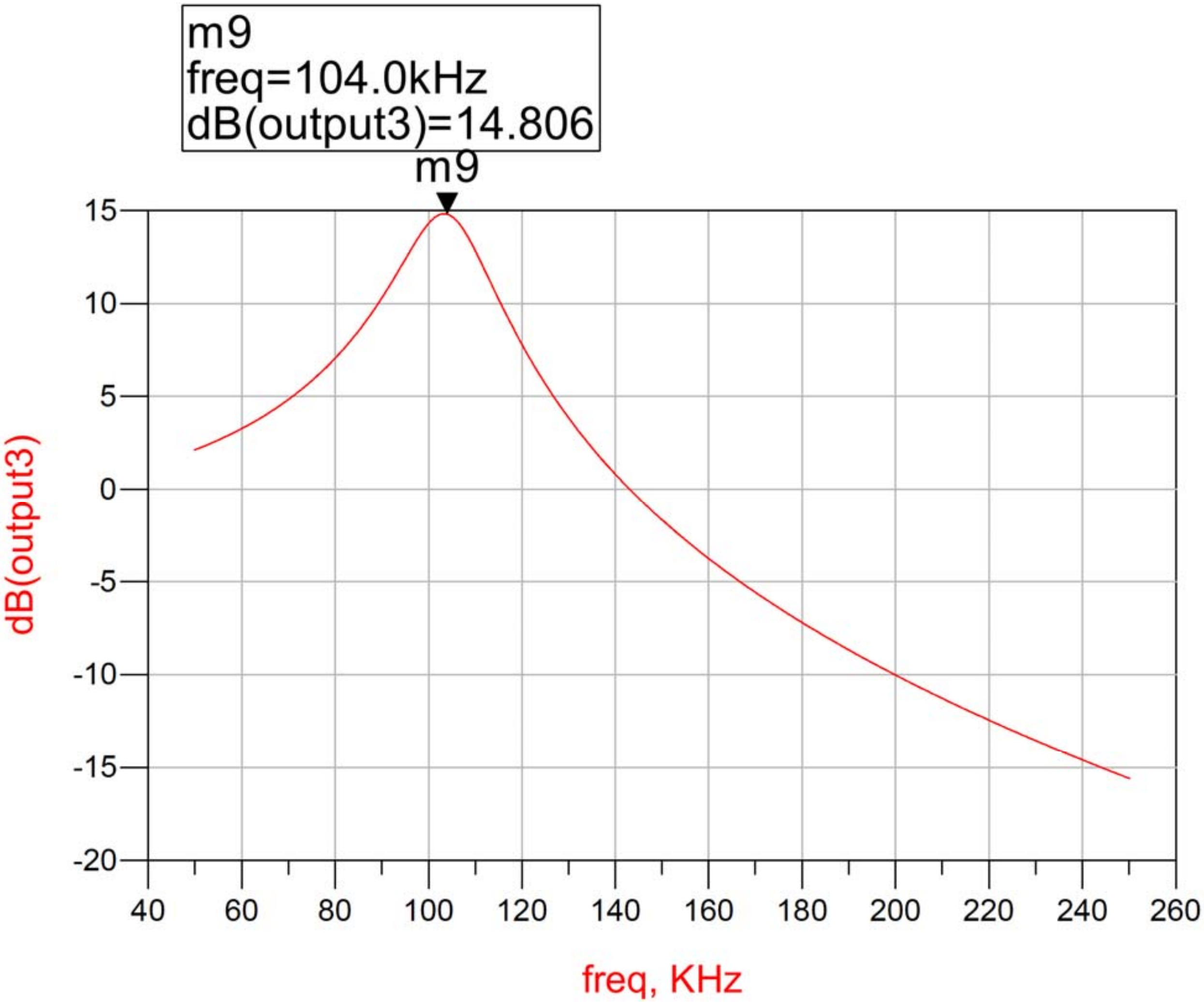
From the polar plot we can evaluate the distance from the singular unstable point 1,0 to each of the three selected data points. We can also evaluate the length of the distance as

Eqn length=mag(1-T)



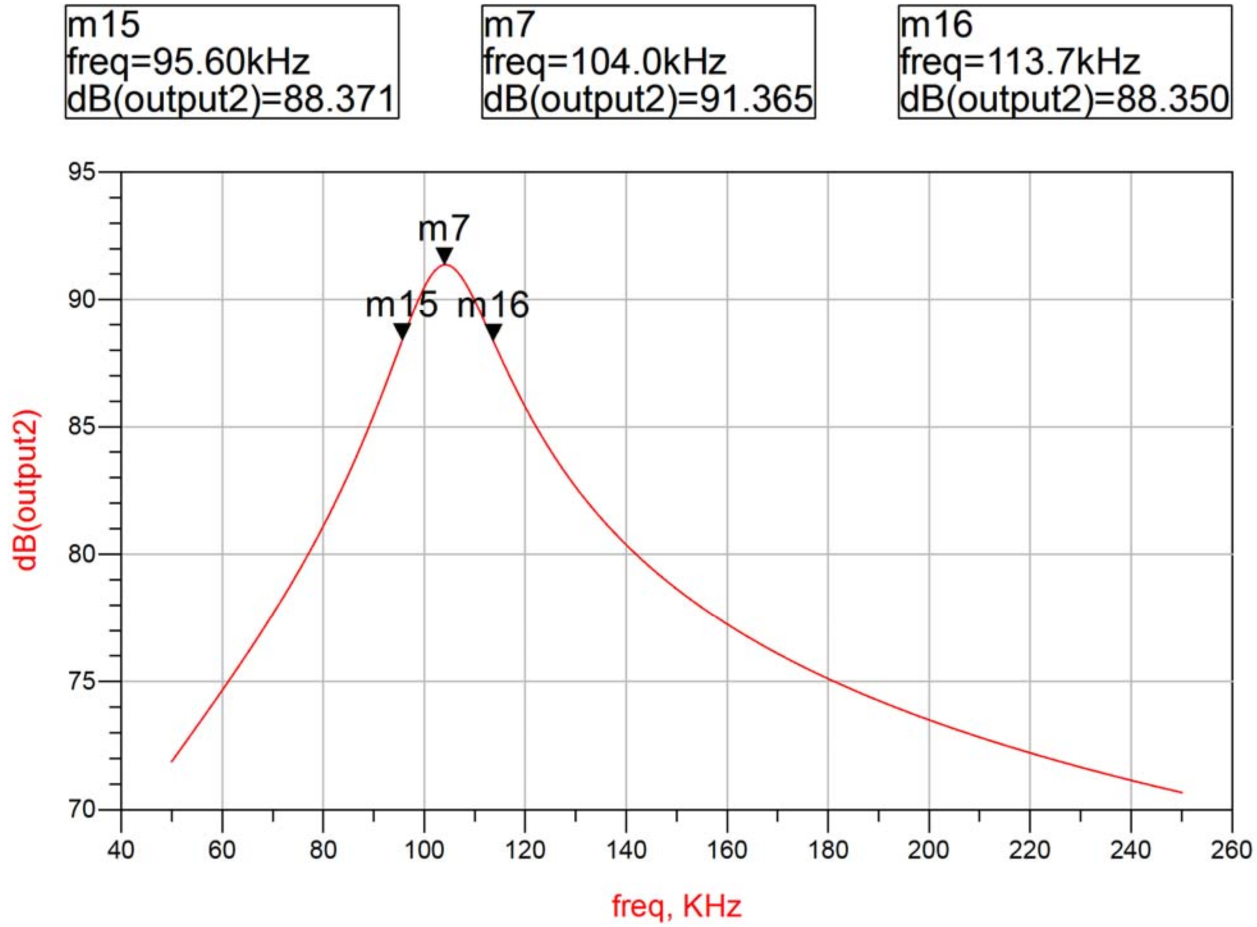
This plot shows the distance from the singular unstable point, 1,0, to the gain curve. The three selected frequencies are identified showing that the point at 104kHz is the closest point to 1,0. This is the LEAST stable point, as it is the closest to the 1,0 point. Note that this is not representative of the bandwidth, phase margin or gain margin.

Evaluating the circuit performance from the closed loop functions can be evaluated by either the output impedance or by the forward transfer function. The forward transfer curve as measured as the output voltage divided by the reference voltage shows a peak of 14.81 dB (magnitude=5.5) at 104kHz.



The forward gain reflects a peak with a magnitude of 14.8dB (magnitude of 5.5) at 104kHz, which is the point closest to 1,0 and is not representative of either the phase margin or the gain margin, nor does it coincide with the bandwidth of 100kHz.

The evaluation of the output impedance indicates a Q of 5.77, very close to that obtained from the forward transfer. The Q should also be represented by the reciprocal of the distance from the singular unstable point, 1,0. In this case the distance at 104kHz is 0.17 and the reciprocal of 0.17 is 5.88



The Q of the output impedance is 104kHz/(113.7kHz-95.6kHz) or 5.76, almost identical to that determined from the length vector. Again this does not reflect the bandwidth, gain margin or phase margin, but the least stable point, as represented by the point closest to the singular unstable point, 1,0.

Conclusion

The assessment of stability is an assessment of the distance of the loop gain curve from the singular unstable point, 1,0. The bandwidth, phase margin and gain margin may represent the closest point, and therefore the stability, or may not. The Bode plot does contain the information required to determine the stability, as can be seen in the polar plot and the length vectors, though it may be difficult to evaluate. The non-invasive measurement is a closed loop assessment of the distance from the loop gain curve to the point 1,0 and always correctly indicates the overall stability, while being non-invasive in that it does not require access to the control loop.

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[i] New Technique for Non-Invasive Testing of Regulator Stability, Power Electronics Technology, Sept. 2011

[ii] When Bode Plots Fail Us, Power Electronics Technology, May 2012