

Common Mode Feedback Analysis for EIT Systems with Distributed Current Sources

D Anton and P J Riu

Department of Electronic Engineering. Centre for Research on Biomedical Engineering. Universitat Politecnica de Catalunya, c./Jordi Girona, 1-3, Edifici C4, 08034 Barcelona, Spain

Email: priu@eel.upc.edu

Abstract. The use of differential voltage measurements is widely used in EIT instruments. Instrumentation amplifiers are always affected by common mode voltages at their input. These voltages may have different origins, being the current sources and multiplexers the ones which contribute the most. However, even considering ideal current sources and multiplexers, some amount of common mode voltage will always be present due to the measurement principle. Errors produced by common mode voltages are very difficult to calibrate because they depend on the object being measured. At low frequencies it is easy to design instrumentation amplifiers with high CMRR values, but common mode voltages are also high, mostly because of unbalances in electrode impedances. At higher frequencies common mode voltages are smaller, but the CMRR of the amplifiers also decreases. Common mode feedback (CMF) to reduce common mode voltages has been largely used in EIT systems. There is a good theoretical understanding of CMF for systems using a single current source and a demultiplexer. However there is a new class of instruments which use distributed current sources. In these systems CMF is actually used to change the inherent unbalance among current sources instead of being applied to the output of the current source. We present a theoretical analysis of this new CMF technique and the results obtained when applying it to our latest EIT system

1. Introduction

The use of differential voltage measurements in EIT reduces the requirements of dynamic range for the acquisition chain. The presence of common mode voltages degrades the performance of the instrumentation amplifiers used to sense the differential voltages. Common mode voltages have different origins, some of which are instrumental: unbalances in current sources, multiplexers; capacitances to ground. However, even with an ideal instrument, some common mode voltage will appear because injection and detection electrode pairs are not symmetrical with respect to the object being measured for most of the used injection/detection combinations in EIT.

A careful design of the instrumentation amplifier will produce a high Common Mode Rejection Ratio (CMRR), but the unbalances in electrode impedances cannot be fully controlled and pose a limit to the achievable CMRR [1]. In addition, errors produced by common mode voltages are difficult to calibrate because they depend on the value of the impedance being measured, and of course, on the frequency [1].

The use of Common Mode Feedback (CMF) has been widely used to reduce these errors. Historically, two main approaches have been used: feedback is applied to the body using an extra electrode [2], or feedback is applied to a point in the current injection network [3]. Like any other feedback application, the network used to apply it must be optimized in order to reduce as much common mode voltage as possible while preserving stability. A comprehensive analysis is performed in [3] for different application points within the current injection subsystem.

A new current injection topology has been recently introduced for broadband systems working at high frequency [4], which avoids the use of current multiplexers. In this new topology, CMF cannot be applied to the current source, because there is a current source for each electrode. Feedback must be applied to some point in the signal generation network to produce an imbalance in the current sources that compensate the common mode voltage. A description of the new topology and a theoretical analysis of the CMF network are presented, along with practical results obtained in our most recent EIT instrument TIE-5sys.

2. Distributed current source topology

A simplified view of the distributed current source is shown in figure 1. A voltage/current converter, based on an AD8130, is connected to each electrode. The V/I converters are driven by a differential/differential amplifier based on an AD8138 through 2 multiplexers. The injection pair is formed by applying the positive output of the amplifier to one V/I converter (source) and the negative output to the other V/I converter (sink). A comprehensive description of the system can be found in [4].

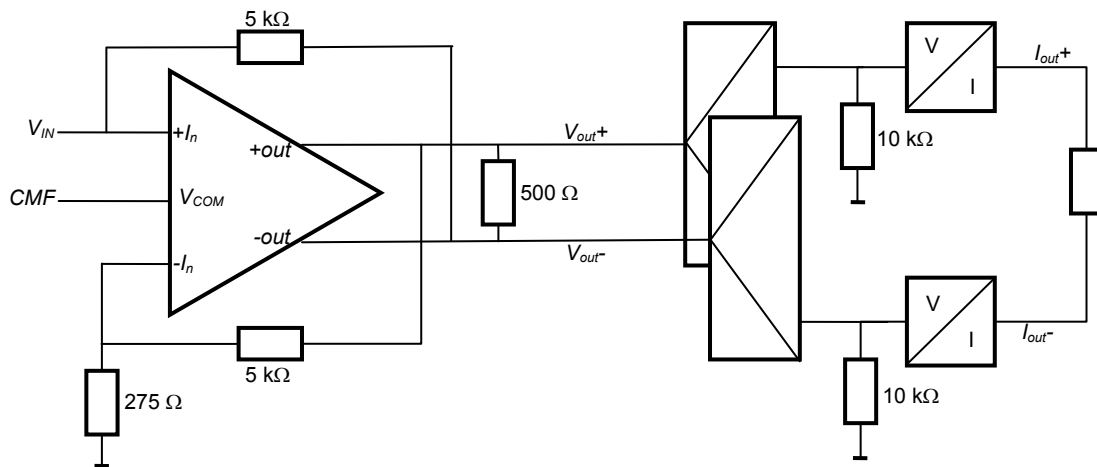


Figure 1. Schematic representation of the distributed current injection system.

The AD8138 provides with an additional input (V_{COM}) whose mission is to produce an unbalance at the output, thus unbalancing the current sources. CMF will be applied to that point. Because this point is not directly connected to the body, the analysis performed in [3] is not valid for this case.

3. Analysis of the feedback network

In order to analyze the stability of the common mode feedback we built a model of the complete injection subsystem, electrodes, body and detection buffers, involving one injection and one detection pair. Because the model is symmetrical, we only analyzed half of it. This model is presented in figure 2.

The different parts of the model have been grouped into logical entities to create the block diagram shown in figure 3. The transfer function of each block was derived, using the actual values for the different discrete components and values from manufacturer data sheets for the IC's. The Common

Mode Feedback amplifier consists on a single op-amp configured as a band-pass inverting amplifier. The high-pass filter is required in order to block any DC values that could revert on saturating the V/I converters. The low-pass filter is required in order to introduce a dominant pole to guarantee stability.

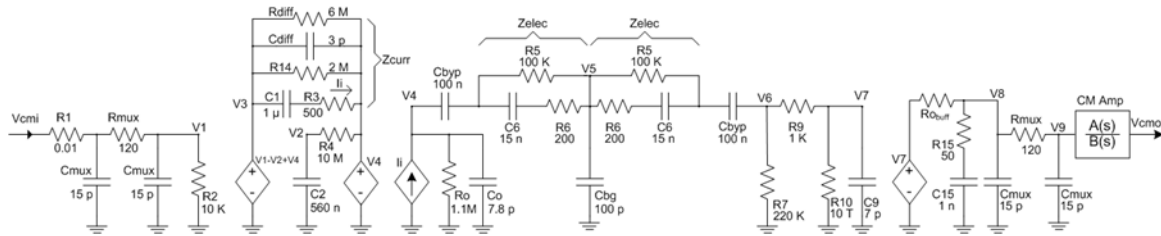


Figure 2. Equivalent schematic representation of one half of the injection/detection channel, showing the voltage demultiplexers, V/I converters, electrodes, buffers, active shielding and the Common Mode Feedback Amplifier

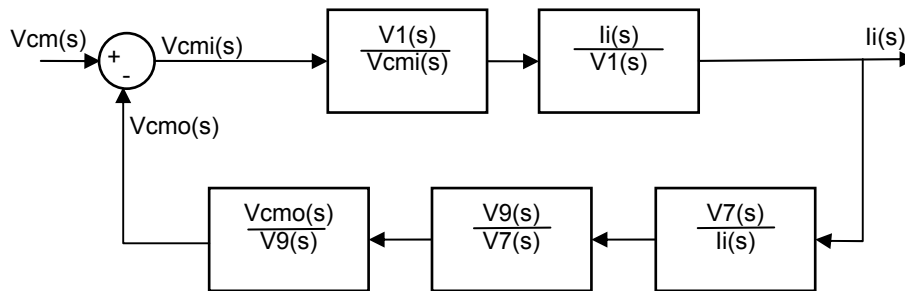


Figure 3. Simplified block diagram of the circuit in figure 2. Names of voltages and currents correspond to those in figure 2.

It is possible to derive an analytical expression for the open loop gain, but it is too cumbersome. Instead, it was numerically computed using actual values for components. The result can be seen in figure 4. This result was obtained using a gain of 0.1 (-20 dB) in the pass-band of the Common Mode Feedback amplifier. The obtained gain and phase margin make the system strongly stable. In fact, gain of the CMF amplifier can be increased by about 13 dB and the system will still preserve the minimum phase and gain margin to be stable. With this latter value, the total gain in the CMF loop will be of about 45 dB. In practice, the gain will have to be adjusted to account for stray capacitances and cable inductances which are difficult to model in an accurate way. A practical problem with the structure used for the CMF amplifier is that changing the gain will also change the frequency response, making the adjustment difficult, so a different implementation may be necessary in the future.

4. Results

To assess the effectiveness of the CMF several measurements were performed in the whole frequency range of operation of the system, with and without the CMF connected. The Systematic Error Ratio (SER) and the Reciprocity Error Ratio (RER)[5] were used to quantify the improvement in accuracy when the CMF was connected. Noise Error Ratio (NER) [5] was also obtained in order to make sure that the noise performance was not degraded when CMF is in operation. All measurements were performed in a resistor mesh test object. The gain of the CMF amplifier was set to 0.03, which was experimentally found to be the maximum allowed to prevent instabilities. Table 1 summarizes these results.

The use of CMF increases the accuracy significantly at low frequency. Above 200 kHz the improvement is less evident and becomes unnoticeable at 500 kHz. This may be expected because at

that frequency the open loop gain is about 40 dB below the maximum. Also, as expected, the effect of CMF on noise performance is unnoticeable.

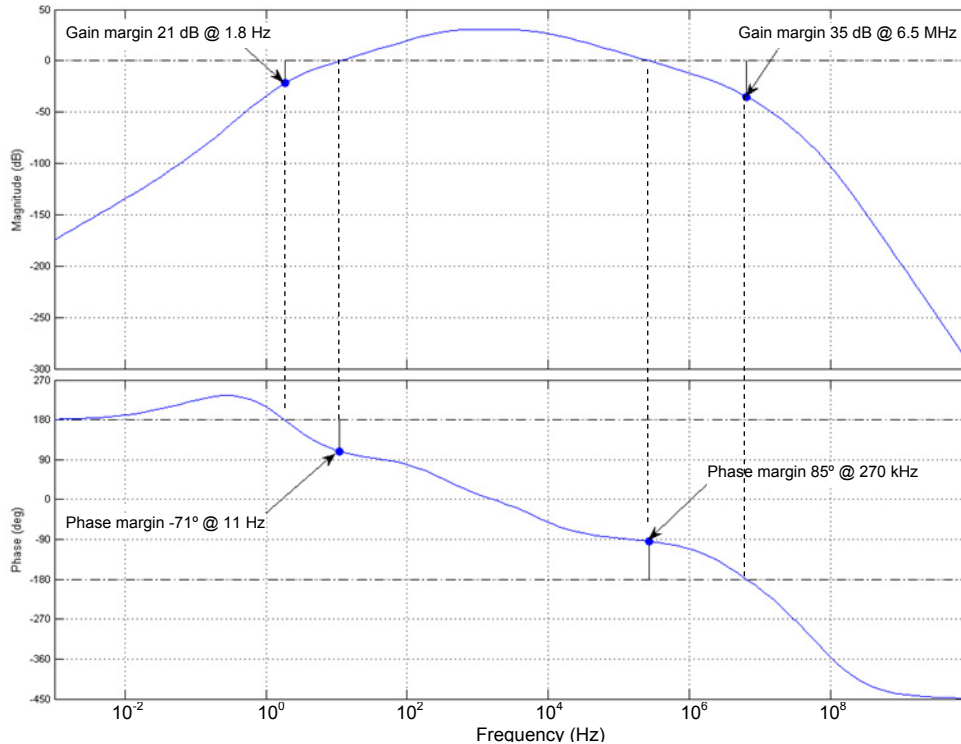


Figure 4. Gain and phase-shift for the open-loop gain of the complete model in figure 2.

Table 1. Summary of performance measurements to assess effectiveness of CMF

Freq.	SER (%)		RER (%)		NER (%)	
	CMF Off	CMF On	CMF Off	CMF On	CMF Off	CMF On
10 kHz	1.76	0.49	3.47	0.74	0.048	0.049
50 kHz	2.12	0.46	3.70	0.66	0.035	0.034
100 kHz	2.29	0.59	3.69	0.63	0.032	0.035
500 kHz	5.75	5.28	3.27	2.38	0.031	0.031
1 MHz	17.88	17.53	2.58	4.91	0.029	0.034

5. Conclusions

Using CMF produced an increase in accuracy in EIT systems. The distributed current source approach has the same tradeoffs between bandwidth, gain and stability in the CMF amplifier that was obtained in more classical approaches. However, the gain of the CMF amplifier on these systems needs to be low, even less than one, in order to preserve stability.

References

- [1] Riu P J, Rosell J, Lozano A and Pallas-Areny R 1995 *Med. Biol. Eng. Comp.* **33** 784
- [2] Rosell J, Murphy D, Pallas R and Rolfe P 1988 *Clin. Phys. Physiol. Meas.* **9** A 93
- [3] Rosell J and Riu P J 1992 *Clin. Phys. Physiol. Meas* **13** A 11
- [4] Anton D, Balleza M, Fornos J, Kos B, Casan P, Riu P J 2007 *IFMBE Proceedings* **17** 564
- [5] Riu P J and Anton D 2010 Performance assessment of EIT Systems *J Phys: Conference Series* (see this issue)