E3.02 – AC4: Instrumentation

Instructor: Christos Papavassiliou, room EE915, c.papavas@imperial.ac.uk
Lectures: Monday 4am (403a), Tuesday 2pm (408)
Books: GH Bryant, Principles of Microwave Measurements (IEE 1993)
T.H. Lee, Planar Microwave Engineering, (Cambridge 2004)
Coursework (25%): Simulation-Lab, ~10 hrs of work. **Due last day of term**

Instrumentation is the science and engineering of measurement. It is the branch of electronic engineering that is concerned with optimising the use of sensors, namely of devices whose electronic properties change according to changes in the physical world around them. Some sensors respond to changes in temperature, others to application of mechanical force on them, others on the magnitude of ambient electric field or magnetic fields. Others, yet, change their electronic properties when exposed to sound, light, humidity, or certain chemicals.

The properties of all electronic devices depend on the external conditions; one may be tempted to think that instrumentation is the same thing as electronics. This point of view overlooks an important distinction: In electronic design a lot of the effort is about minimising the influence of external factors on the circuit output. Instrumentation, on the other hand, strives to maximise the effect of external influences on the output.

Instrumentation is everywhere: A radio or television receiver includes an electromagnetic field measurement instrument. The computer disk drive contains a magnetic field meter to read the disk magnetisation. The computer keyboard consists of a large number of the keys, which are tactile sensors, usually capacitance meters. The computer mouse includes a light detector, and so on.

To be able to interface the physical world to electronics we need at least a superficial familiarity with the techniques used to detect the different physical quantities. The course, therefore, starts with some physics in order to review what sensors and measurements are.

Idealised measurements and associated circuits are of little use in the science of instrumentation. The real world is noisy. Much of the effort in instrumentation and advanced electronics, for that matter, is expended in attempts to minimise the effect of noise. We will spend a good deal of effort studying noise in components, sensors and electronic circuits. We will learn how to calculate noise and how to optimise the signal to noise ratio in an application. We will also study some elementary signal processing which can be used to minimise the effect of noise in a measurement.

Elementary electronics courses focus on the manipulation of voltages and currents. Yet, the most accurate measurements presently possible are those of time and frequency. For this reason we study time and frequency measurements. Time measurements require clocks, and clocks in electronics are known as oscillators and synthesisers.

Linearity seems to underline all elementary discussion of electronics. Yet, no instrument or sensor is perfectly linear. Correcting for the nonlinear response of a sensor is often so straightforward that it is not worth the effort engineering a more perfect instrument. We will therefore study modelling, interpolation and regression, namely the mathematics of fitting curves to data. These procedures are behind the various calibration schemes used by commercial instrument suppliers.

The second half of the course will be a survey of a number of measurement techniques. Some of these are elementary, like the oscilloscope. Others are more advanced and include lock-in amplifiers, spectrum analysers, interferometers, transfer oscillators, network analysers. We will discuss the principles, physics and mathematics of operation of these instruments, and also their performance capabilities and limitations.

The mathematical content of the course varies between superficial phenomenology and the usual mathematics of circuit analysis, including linear algebra and Fourier/Laplace transforms and the occasional differential equation.

We will cover topics from the following list, in varying depth and detail:

1. Sensors/Transducers; Bridges
2. Noise, system noise, noise matching
3. Signal Amplification; autozeroing and chopper amplifiers.
4. Oscillators, synthesizers, integer and fractional PLL, transfer oscillators.
5. Frequency and time measurements
6. Modelling and data fitting; Calibration
7. Sampling, oversampling, subsampling. Aliasing and anti-alias filters.
8. A/D and D/A Converters. Quantisation noise.
9. Synchronous measurements and Interferometry
10. Radio frequency measurements