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GOUBAU LINE BEAM INSTRUMENTATION TESTING, THE BENEFITS

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Abstract

At JLab and Bergoz Instrumentation Goubau lines are used for beam instrumentation testing. A Goubau line differs fundamentally from standard bench testing techniques in the way it produces the electromagnetic fields which interact with the DUT. This allows to acquire complementary information about DUT characteristics. Consequently, we improve our knowledge about the DUT. At JLab BPM responses have been successfully mapped and at Bergoz Instrumentation high-frequency behavior of current transformers is under study. We present results, highlight benefits and outline ideas for future studies of additional accelerator components.

INTRODUCTION

A Goubau line [1–3] allows to overcome some of the limitations of other bench testing techniques used to characterize beam instrumentation. It makes mapping of beam position dependence easy and measurements are free of spurious resonance even at GHz frequencies. Hence, the Goubau line is particularly suitable for beam position monitor (BPM) mapping or the study of high-frequency behavior of current transformers (CTs) and other accelerator components.

The Goubau line is based on the principle of surface waves which has been first described by A. Sommerfeld more than a century ago [4]. Due to realistic boundary conditions any wire can act as a wave guide for a TM_{01} mode, which surrounds the wire. Since no outer conductor is required to guide the wave, setups based on this principle are also known as single wire lines.

The TM_{01} mode consists of a radial electric field component E_r, an azimuthal magnetic field component H_ϕ and a weak longitudinal electric field component E_z. Nearby the wire field strength is inversely proportional to distance, further away field strength decays exponentially. Exact field parameters depend on frequency and wire properties. Most notably, a dielectric coating, i.e. an insulation, helps to guide the fields. In practice the exponential decay starts at distances sufficiently far from the wire. Consequently, over the aperture of normal beam instrumentation the electromagnetic field on the Goubau line resembles closely the electromagnetic field of a charged particle beam.

The field on the Goubau line is excited by antenna cones. Geometry of these cones defines launching efficiency and lower cut-off frequency. Fig. 1 shows a sketch of a Goubau line. More details on the Goubau line principles can be found in [1–3] and references mentioned therein.

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In the following we discuss the application of the Goubau line for BPM and CT measurements. Ideas for measurements of other accelerator components are outlined.

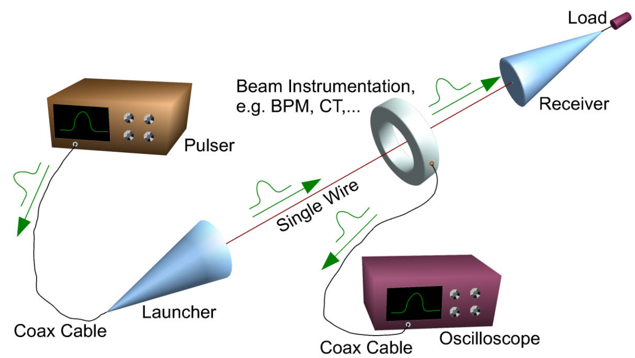

Figure 1: Sketch of a Goubau line.

BEAM POSITION MONITORS

To map a BPM pick-up response basically any field source is sufficient that can be exactly moved within the aperture. Absolute field strength is of minor importance. Usually this source is a wire or another type of antenna. But when also the BPM read-out electronics should be qualified, absolute field strength does play a role due to non-linear electronics response. Hence, it is preferable if field strength is position independent.

The Goubau line provides such characteristics. The wire acts as a field source that can be freely moved within the BPM aperture. Field strength shows just a weak dependence on BPM position due to different reflections at the BPM body. Frequency can be adjusted to the operating frequency of the BPM just by tuning the signal generator. Furthermore, no parts need to be adjusted to a certain device geometry; except for the devices holders.

A device built of DN63 flanges with 35mm aperture has been put on the Goubau line at Bergoz Instrumentation. Signal transmission for frequencies up to 3 GHz was measured while moving the device. It was found that signal transmission changes only by a few 0.1 dB over the full frequency range when moving the device 10 mm off-center. In any case, since the Goubau line allows to measure signal transmission, any influence of absolute field strength can be adjusted for, either mathematically or by adjusting input power.

Measurements

Special BPMs are required for the new CEBAF Hall C compton polarimeter. Each consist of four button electrodes mounted on a flat, wide chamber of 95 mm width and 19 mm height (Fig. 2). Such a geometry makes positioning of the buttons and consequently BPM response sub-optimal. The

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buttons are not orthogonal and the usual difference-over-sum or log-ratio algorithms will lead to a highly non-linear deviation of the real beam position.

Figure 2: Photo of the BPM.

The BPM has been tested on the Goubau line at JLab. The goal is to establish a response map allowing accurate determination of beam position. Input signal is a sine-wave at the CEBAF RF frequency of 1497 MHz. The central part of the BPM aperture is scanned automatically by motorized movers over a range of $x = \pm 10$ mm, $y = \pm 5$ mm. Electrode voltages are averaged and recorded. Fig. 3 shows superimposed contour and surface plots of the four electrode signals.

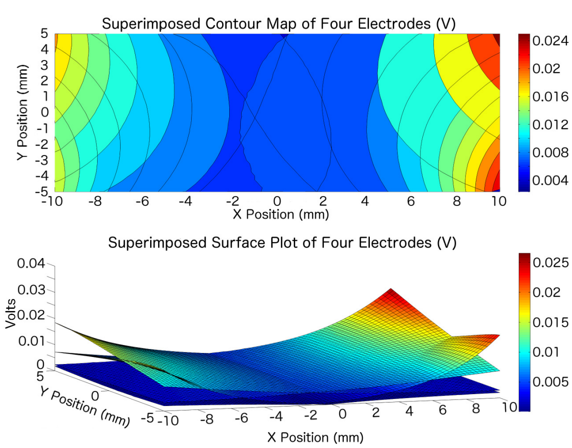

Figure 3: Responses of the four BPM electrodes.

The plots show an offset between scan origin and real center of the BPM, which is not relevant. A relevant result is that the electrodes show slightly different responses; contour lines are not symmetric around the BPM center. Computer simulations or analytical models would most likely miss this important information. Not because of principle limits, but they would be usually based on unduly simplified models. Nevertheless, it is foreseen to compare measurement results to an analytical model.

Another relevant, though expected result is that y-sensitivity is reduced close to the BPM center; signals are weak and contour lines tend to be parallel to the y-axis. This is a consequence of BPM geometry.

Studies will continue to understand better the BPM performance and its limits.

CURRENT TRANSFORMERS

Limits on current transformer performance can be split in two categories. On the one hand, there are limits stemming from the current transformer itself, e.g. core losses or resonances due to housing geometry. These are real limits that will also be present in the accelerator when measuring beam. On the other hand, there are limits stemming from the laboratory measurement setup, e.g. impedance mismatches or resonances in the setup. These aggravate adequate CT characterization in the workshop. Consequently, they also hinder any study of the real CT limits.

The Goubau line does not show the same limits as standard measurement techniques, i.e. 50 Ω contraptions that are also known as "spiders". It provides proper information about the CT response in the GHz range, including beam position dependence. But it lacks the capability to measure at low frequencies. The lowest frequency for which the Goubau line at Bergoz Instrumentation provides usable information is around 300 MHz. Spiders, on the other hand, are capable of delivering information up to this frequency and even some 100 MHz beyond. But they cannot be used in the GHz range. Hence, both methods, spider and Goubau line, can be combined to obtain proper information about the full CT response.

Performing high quality measurements with a Goubau line is more complicated for CTs than for BPMs due to the fact that knowledge of absolute field strength is more important. Well-adapted launching and receiving cones, which show low signal reflections, minimize standing waves on the Goubau line. Power of the wave on the Goubau line can be extracted from reflection and transmission measurements. Wave impedance can be calculated applying the theoretical equations [1]. Taken together this allows to get the equivalent CT response as if it were measured in a 50 Ω environment.

Measurements

As an example a CT has been measured in a spider and on the Goubau line. Fig. 4 shows the CT response in the spider. Obviously, beyond 1 GHz this measurement is useless. Having only this information at hand would usually mean that the CT output should be low-pass filtered to force a cut-off of the noisy part. Consequently, this particular CT would artificially be adjusted to have an upper cut-off frequency below 1 GHz.

Fig. 5 compares the high frequency part of CT measurements performed in the spider and on the Goubau line.

Below 500 MHz there is a small residual ringing in the Goubau line measurement, which is due to standing waves. Between 500 MHz and 1 GHz both measurements match.

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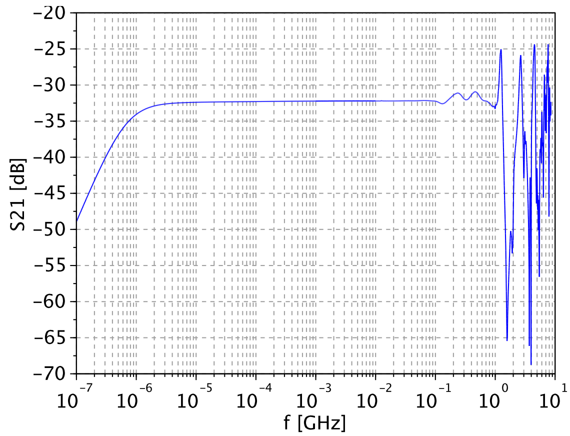

Figure 4: CT response as measured in the spider.

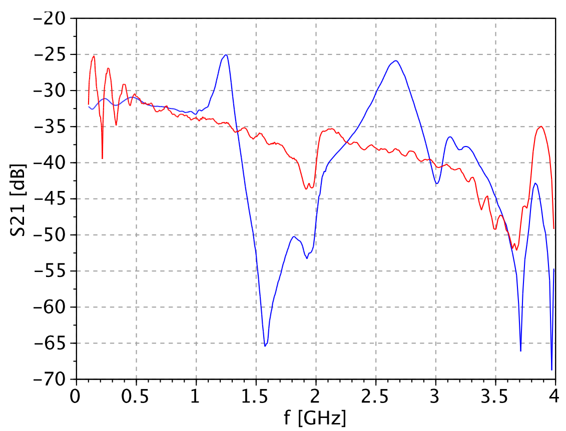

Figure 5: Comparison of the high frequency CT response obtained in the spider (blue) and on the Goubau line (red).

Starting from 1 GHz up to about 3 GHz they behave totally different. The spider measurement contains several resonance of huge amplitude. On the other hand, the Goubau line measurement shows only a single, comparably weak resonance around 2 GHz; in general the CT response just slowly fades. Above 3 GHz the two measurements are again similar.

Having the additional information from the Goubau line changes completely the interpretation of the real CT performance. The 2 GHz resonance and a resonance close to 4 GHz, which might just be a harmonic, are visible in both measurements. Hence, one can conclude that these are real CT resonances. There are no other strong resonance that need to be cut off by low-pass filtering. Actually, the CT already shows a behavior as if it were low-pass filtered with an upper cut-off frequency of about 1.3 GHz. Consequently, combining the two measurements reveals that the bandwidth of the CT ranges from 710 Hz to 1.3 GHz.

To improve bandwidth, only two effects need to be identified and mitigated. The first is the cause of the low-pass filtering; most likely stray capacitance. The second is the cause of the 2 GHz resonance. Often these resonances are due to resonances within the CT housing. However in this case dimensions of the housing do not fit to this frequency, but the dimensions of the magnetic core do.

Having identified these two limitations on CT performance allows to continue with a systematic study of their causes, which will start in the near future.

CONCLUSION AND FUTURE IDEAS

We presented examples for the practical application of Goubau lines; a BPM measured at JLab and a CT measured at Bergoz Instrumentation. In both cases the Goubau line allowed to perform accurate measurements in a quick and simple way. This leaves more time for a proper interpretation of results and may be an amelioration of the devices.

For the BPM we have shown that the Goubau line is sensitive enough to reveal small differences in electrode responses. For the CT we have shown that the Goubau line provides information often inaccessible with standard measurement techniques.

Generally, the practical application of a Goubau line is not complicated. It is the theoretical background which is based on uncommon effects and thus rather tedious to understand; an effort which is often not even required for the practical application.

For the moment only BPMs and CTs have been tested on the Goubau line. But of course its application is not limited to these two instruments. Any component that interacts with the electromagnetic fields of a charged particle beam could in principle be tested; even at frequencies that surpass current measurements. There is no principle limit on maximum frequency. Though a practical limit stems from the mechanical accuracy of launching and receiving cones.

For example, it might be possible to excite fundamental and higher-order modes in cavities. The corresponding frequencies might be identifiable by their impact on transmission and reflection measurements.

Another possibility could be the qualification of a series. Only few devices would be characterized extensively. The rest would just be compared to a signature.

ACKNOWLEDGMENT

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REFERENCES

[1] G. Goubau, "Surface Waves and their Application to Transmission Lines", J. Appl. Phys. 21, 1950.

[2] J. Musson et al., "Application of Goubau Surface Wave Transmission Line for improved Bench Testing of Diagnostic Beamline Elements", in Proc. of PAC09, 2009.

[3] F. Stulle, J. Bergoz, "Surface Waves for Testing of Beam Instrumentation", in Proc. of IPAC12, 2012.

[4] A. Sommerfeld, "Ueber die Fortpflanzung electrodynamischer Wellen längs eines Drahtes", Ann. Phys. 303, 1899.