Standard setups for bench testing of beam instrumentation in the workshops usually fail when it comes to signal frequencies a lot higher than 1 GHz. A potential improvement could be provided by electromagnetic surface waves traveling along a single wire. These waves consist of the fundamental TM mode and resemble closely the radial electric and azimuthal magnetic fields around a long and thin beam of charged particles. We discuss their fundamental properties, show how they could be applied and compare calculations to measurements up to 8.5 GHz.

Maxwell’s equations allow a single wire to act like a wave guide that has been turned inside out.

- The EM wave on the wire needs to be properly excited.
- For example, by using a tapered cone.
- It has to perform the matching of the mode on a coax cable, i.e. a quasi-TEM mode, to the TM mode on the Goubau line.
- Additionally, the cone needs to follow a well-defined impedance profile to avoid internal reflections. Shapes like this are known as transmission line taper, e.g. Klopfenstein or Hacken taper. The wire can be a standard enamel coated copper wire. Its thickness and the thickness of its coating will influence the field extension.

There is an additional $E_0$, but it is weak.

- Near the wire the radial electric and azimuthal magnetic field are proportional to $1/r$.
- Further away from the wire the fields decay exponentially.

- Hence, the wave is non-radiating; it is bound to the wire.
- Maxwell's equations allow a single wire to act like a wave guide that has been turned inside out.

Many thanks to J. Musson, JLab for providing the cones.

A fundamental TM mode outside a wire of radius $r_1 > r_2$:

$$H_z = \frac{\sqrt{r_2}}{\sqrt{r_1}} H_0^{(1)}(x)$$

like the fields around a charged particle beam

$$E_z = \frac{\sqrt{r_2}}{\sqrt{r_1}} E_0 H_1^{(1)}(x)$$

propagation constant of a free wave

$$\gamma = \frac{\omega}{c} \pm \frac{2\pi}{\lambda}$$

propagation constant of the guided TM mode

$$\gamma = \frac{\omega}{c} - \frac{2\pi}{\lambda}$$

Harmonic current $I$ associated with the TM mode on the Goubau line.

Received Load SignalCoax Cable Receiver Signal Generator Coax Cable Oscilloscope Launcher Beam Instrumentation, e.g. BPM, CT, ... A Goubau line for bench testing of beam instrumentation.

A current transformer (CT) measured in our standard setup (= “spider”).

- The CT was not tuned to achieve a flat response, but has been simplified in the hope to get useful signals at as high frequencies as possible.
- SW, its upper cut-off frequency (~3dB) is at 1 GHz followed by a steep drop.

- The CT response is lower than in a “spider” because the impedance of the Goubau line is higher than 50 Ohm. Hence, for the same input power the current is lower.

- The CT response in a “spider” (blue) and CT response in our Goubau line normalized to a 50 Ohm environment (red).

- CT response in a “spider” (blue) and CT response in our Goubau line normalized to a 50 Ohm environment (red).

- Since the Goubau line transmission is pretty flat one might expect a good CT measurement. But standing waves between the cones spoil the measurement.

- Measured reflection of our Goubau line (red) compared to calculated reflection of a single cone (blue).

- Standing waves on the Goubau line lead to oscillations.

- From measurements we learned a lot and we could confirm our expectations.

- Reflections by the cones are limiting performance. Their shape and especially the shape of the conductors inside them need to be improved.

- Standing waves on the Goubau line lead to oscillations.

- Though, most importantly we understood what has to be improved.

- The same current transformer measured in our Goubau line.

- Reflections between the cones lead to standing waves which induce a ±1dB ripple in the CT measurement.

- Nevertheless, the CT response lies within ±3dB up to 3 GHz.

- On a 1 GHz the agreement is good since the “spider” works well and the cone reflection is low.

- Obviously, around 2 GHz there is an artifact in the “spider” measurement, which is absent in the Goubau measurement, i.e. the CT is o.k.

- It is a known problem of the standard setup that it distorts measurements at high frequencies.

- This is the main motivation for studying the Goubau line.