A Goubau Line for Bench Testing of Beam Instrumentation

Outline

Motivation ➔ Motivation

Surface Waves ➔ EM Surface Waves on straight round wires

Goubau Line ➔ Goubau Line

Application ➔ Application to Beam Instrumentation

Summary ➔ Summary
Outline

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Surface Waves

Goubau Line

Application

Summary

In the Workshop

Beam Instrumentation

Signal

Cable

Signal Generator

Do they match?
A possible Improvement

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Some History

1909

“On the propagation of electrodynamical waves along a wire”

1907

“Electromagnetic waves on a wire with insulating cylindrical shell”

1909

“Electromagnetic wire waves”

Surface Waves and Their Application to Transmission Lines

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Main Results

A. Sommerfeld: “Taking into account the finite conductivity of a straight, round wire, a possible solution of Maxwell's equations is a surface wave that travels along the wire and is non-radiating. This will be a TM wave at least consisting of the fundamental mode.”

F. Harms: “The conductivity does not have to be finite, if the surface of the wire is coated with a dielectric.”

D. Hondros: “Only the fundamental TM mode will travel, all higher order modes will be strongly damped.”

G. Goubau: “Here is a bunch of math that describes surface waves on wires including some new insight into their physics. I also have an idea how to easily excite them and show a possible application to transmission lines.”
a fundamental TM mode outside the wire:

\[
E_r = i A \frac{h}{\gamma} H_{1}^{(1)}(\gamma r) e^{i(\omega t - h z)}
\]

\[
E_z = A H_{0}^{(1)}(\gamma r) e^{i(\omega t - h z)}
\]

\[
H_{\phi} = i A \frac{k^2}{\omega \mu \gamma} H_{1}^{(1)}(\gamma r) e^{i(\omega t - h z)}
\]

\[
\gamma^2 = k^2 - h^2
\]

propagation constant of guided wave
Almost all values are known due to wire and signal properties. Only $\kappa$, which is the propagation constant of the signal moving along the wire, has to be calculated...

Please look at the Goubau paper for some pretty tedious math... (...and if you can stand more than that, Sommerfeld, Harms and Hondros are nice too (but in German)...)
The phase velocity of the signal on the wire is always lower than the speed of light and $\gamma$ will always be complex.

For small $\gamma r$ the Hankel function $H_1^{(1)}(\gamma r)$ drops with $1/(\gamma r)$.

For large $\gamma r$ the Hankel function $H_1^{(1)}(\gamma r)$ drops with $e^{-\gamma r}$.

Hence, the surface wave is non radiating.

By adjusting the properties of the wire and its dielectric coating the extension of the field can be adjusted, i.e. the point of transition from $1/(\gamma r)$ to $e^{-\gamma r}$.

Near* the wire the field distribution is very similar to the fields around a charged particle beam.

Unfortunately, $\gamma$ is approximately proportional to the frequency.

*What “near” means depends on $\gamma$, it can be anything from nanometers to kilometers. Fortunately, for rather normal wires and coatings it is around centimeters assuming GHz frequencies.
O.k. That sounds all very nice. But how do we produce the wave?

Easy! We only need to remember that in a real coax cable a quasi-TEM mode will travel, i.e. a TM-mode with vanishing longitudinal component for zero frequency and otherwise very small longitudinal component (neglecting it is o.k. = TEM mode).
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A possible Setup

- Launcher
- Coax Cable
- Goubau Line
- Beam Instrumentation, e.g. BPM, CT, ...
- Receiver
- Load
- Signal Generator
Benefits

➔ The power travels along a single wire and is dumped in a load. No return wire needed.

➔ Only the launching horn is grounded. The receiving horn and the load are floating.

➔ Launcher and receiver provide good impedance matching of Goubau line to signal generator and load.

➔ All that should result in an improved impedance behavior up to high* frequencies.

➔ And we should have a better control of the power flow through the device under test, shouldn't we?

*A principle limit is that the phase velocity gets too slow at really high frequencies, but that's usually in the THz regime. A practical limit at 10 GHz to 100GHz is due to field extension.
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A closer Match


at JLab it works: M. Spata et al., TUPC172, IPAC11