APPLICATION OF GOUBAU SURFACE WAVE TRANSMISSION LINE FOR IMPROVED BENCH TESTING OF DIAGNOSTIC BEAMLINE ELEMENTS*

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Abstract

In-air test fixtures for beamline elements typically utilize an X-Y positioning stage, and a wire antenna excited by an RF source. In most cases, the antenna contains a standing wave, and is useful only for coarse alignment measurements in CW mode. A surface-wave (SW) based transmission line permits RF energy to be launched on the wire, travel through the beamline component, and then be absorbed in a load. Since SW transmission lines employ travelling waves, the RF energy can be made to resemble the electron beam, limited only by ohmic losses and dispersion. Although lossy coaxial systems are also a consideration, the diameter of the coax introduces large uncertainties in centroid location. A SW wire is easily constructed out of 200 micron magnet wire, which more accurately approximates the physical profile of the electron beam. Benefits of this test fixture include accurate field mapping, absolute calibration for given beam currents, Z-axis independence, and temporal response measurements of sub-nanosecond pulse structures. Descriptions of the surface wave launching technique, transmission line, and instrumentation are presented, along with measurement data.

INTRODUCTION

Beamline elements are frequently evaluated during design and development, as well as for production compliance and performance consistency. Typical tests involve an antenna structure concentric with the component under test. Measurements often include basic alignment, go/no-go tests of RF pickups, and preliminary X-Y field mapping. Since single-wire antenna systems exhibit high VSWR, they are not representative of a particle beam, and possess Z-axis dependencies.

More desirable information results from a bench test which more closely resembles the actual in-situ environment. This can be accomplished by the use of transmission structures, possessing minimal radiation, loss, and VSWR. Traditional component studies have demonstrated coaxial techniques, whereby the beam pipe serves as the outer conductor, and an inner conductor is added to resemble the beam [1]. This technique poses a problem for field mapping, since the larger diameter of the inner conductor limits the scan range. Also, there is significant ambiguity in determining the electrical centroid of the conductor. Reducing the inner conductor diameter to ~200 um results in a coaxial transmission line having a large impedance value, requiring awkward conical impedance matching devices to be attached to the component under test [1]. Pickups and other elements installed on the inner surface of the beamline component may also affect the intrinsic impedance.

S-parameter techniques involving double-step topologies have seen popularity, which are superb at accurately mapping the device under test. Since extensive de-embedding and post-processing are required, this test fixture does not easily support receiver testing [2].

SURFACE WAVES

Experiments performed by Sommerfield in 1899 demonstrated that particular dielectric boundary conditions permit the existence of a travelling wave, trapped on the surface of a cylinder having finite conductivity [3]. In general, these SW modes are non-radiating, encounter minimal dielectric loss, and result in fields which decrease as 1/r in the radial direction [4]. SW phenomena were not generally exploited until 1954, when methods for successfully launching and capturing these waves were proposed by Georg Goubau, as a substitute for low-loss coaxial microwave transmission systems [4].

The Goubau Line, or G-line system, is comprised of a single conductor, surrounded by a thin dielectric. The boundary layer, combined with imperfections in the conductor surface, is responsible for supporting the surface wave, and subsequent travelling wave. The launcher serves to excite the proper fields for SW formation, as well as to transform the impedance from 50 Ohms to that of the single conductor, nominally 200 Ohms. The conical shape of the launcher, combined with a gradual taper of the inner conductor, achieves the proper conditions. Figure 1 demonstrates the SW development within a metal cone.

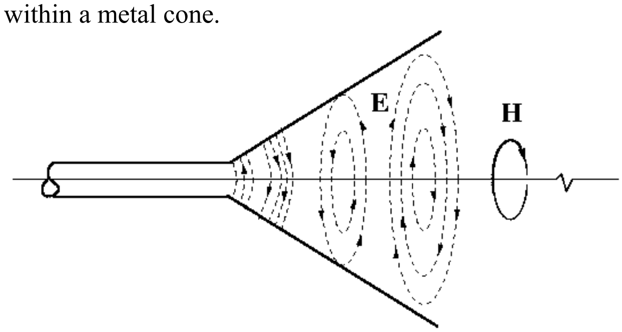

Figure 1: Surface wave evolution inside the launching cone.

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Horn diameter and taper are somewhat empirical, with the final horn radius roughly equal to the radius encompassing the 1/r field characteristic. Nomographs can be used to simplify the design process, subsequently leading to experimental optimization; ranges between $\lambda/4$ and λ are typical.

Taper is a function of limiting higher order modes, while maintaining the proper planar wavefront [5]. Empirical diameter-to-length (D/l) ratios have been published, ranging from 0.4 to 1, which serve well as design baselines [6].

Prototype

A prototype G-line was loosely patterned after Goubau's UHF SW description, using the inner conductor of RG-174 coaxial cable, and brass shim stock for the launchers [7]. A design nomograph predicted a nominal wire impedance of 225 Ohms for the polyethylene-coated conductor [8]. A second nomograph was consulted, which prescribed a horn radius of 5 cm, given λ = 20 cm and conductor with 1.5 mm diameter (wire plus dielectric) [5]. A D/l ratio of 0.4 was empirically chosen for the horn, resulting in a cone diameter of 5 cm and a length of 14 cm. No other form of matching was included in the preliminary design. Insertion and return losses were measured using an Agilent E5017 network analyzer, and although the performance was sub-optimal, the SW mechanism was clearly present.

BPM G-Line

Subsequently, collaboration resulted in locating and adapting a commercial system intended for distributed wideband communication systems, under the trade name RadWire by Rubytron [9]. Preliminary measurements of the flared horn resulted in a diameter of 10 cm, and D/l ratio of 0.54. The non-linear, exponential-like taper facilitates a broadband impedance transition from 50 Ohms to the higher wire impedance [6]. The inner conductor is tapered, mating with the supplied enamelled #14 AWG conductor. A nominal 250 Ohm impedance is predicted for the 1.6 mm wire diameter [4].

The RadWire system was assembled atop an optical bench, along with an X-Y stage, possessing <10 um resolution. Reciprocal s-parameter measurements were performed, in order to fully characterize the G-line configurations, and evaluate the launching process. In addition, all tests were performed with and without a sample 4-wire BPM (terminated), typical of JLAB installations, in order to observe the effects of SW perturbations. Aside from energy extraction at 1497.0 MHz from the nominal 15 dB coupling factor, minimal impact was observed over the entire 8 GHz frequency range.

The RadWire is remarkably broadband, exhibiting a nominal 3-4 dB insertion loss, and flat S21, as shown in Figure 2, consistent with predictions in the literature [6].

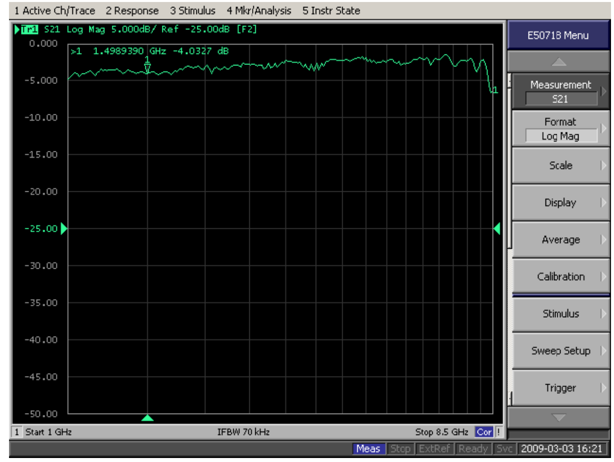

Figure 2: Insertion loss (S21) plot of 1.6 mm diameter RadWire, demonstrating broadband SW characteristic with 3-4 dB nominal loss.

Return loss was nominally greater than 10 dB (VSWR = 2:1) over the 1 – 8 GHz sweep range, a desirable trait for pulsed RF measurements. A VSWR of 2:1 implies 88% of the energy is transferred to the transmission line system. Figure 3 shows the S11 plot, exhibiting minimal structure, thus implying good transmission line characteristics.

Figure 3: Return loss (S11) plot of 1.6 mm RadWire, showing nominal 10 dB or better (VSWR < 2:1), over 8 GHz.

In an effort to more closely model the 200 um diameter of the CEBAF electron beam, #34 AWG enamelled magnet wire (δ = 160 um) was substituted for the RadWire conductor, and again measured. Extensions were required to complete the taper, and clear enamel was applied to the soldered surfaces to ensure the presence of dielectric. S21 data is shown in Figure 4.

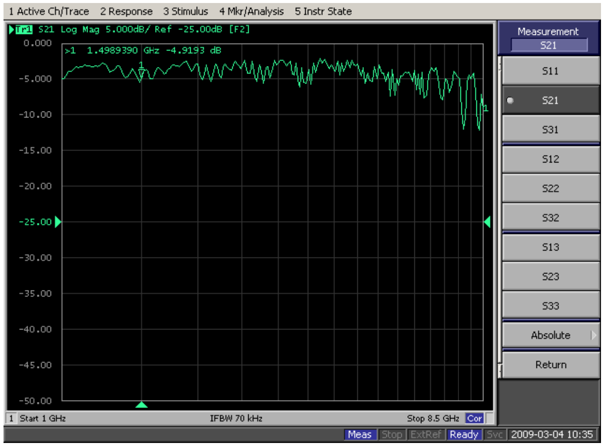

Figure 4: Insertion loss (S21) plot of 160 um diameter RadWire, demonstrating broadband SW characteristic with 4 dB nominal loss.

S11 data was nearly identical to the #14AWG, except for a degradation of 2dB, while retaining the same structure as before over 8 GHz. This likely explains the slight difference in the S21 plot, but the utility of the 160 um G-line is apparent.

In operation, either of the launchers would be replaced by a cylindrically-symmetric load, such that it may be threaded through the beamline element under test.

CONCLUSION

Traditional bench testing techniques will be inadequate to characterize beamline components and assess performance of receiver systems. The use of the G-line facilitates measurements which more accurately mimic electron beam conditions. This system is particularly well-suited for our bench system, due to ease of fabrication, low-cost, and choice of operating frequency range. In addition, due to the flat 8 GHz frequency response, pulsed beam structures can be replicated, providing a platform for receiver development. Further reduction of VSWR is planned, in order to minimize dispersion of pulses resulting from reflections. Finally, the use of ~1 um X-Y stages presents a system which can be automated, improving repeatability and simplifying test procedures.

ACKNOWLEDGEMENTS

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