EM PROPAGATION IN JET ENGINE TURBINES

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Abstract

There is interest in the propagation of EM signals inside jet engine turbines for a number of reasons. Applications include radar scattering phenomenology and jet engine plasma plume formation studies. In our research, we are interested in the communication channel characteristics for micro-size wireless sensors attached to the turbine blades that measure parameters such as strain and temperature.

Propagation measurements were performed on both F-16 (F-110) and Boeing 747 (CF6-50) turbines. The frequency band extended from 2 to 20 GHz (wavelengths longer than the turbine blades to wavelengths shorter than the gap between turbine blades). Signals were propagated with both radial and circumferential polarization. Both transmission and scattering measurements were made from both the inlet and the outlet. We also used small probe antennas inserted in boreholes between turbine stages. A range of blade positions were included.

We will show the propagation characteristics as a function of polarization, frequency and time (UWB time domain transformations). We will also show the internal radar reflection characteristics of the turbine as a function of various stator blade rotation angles. Comparisons with a hybrid mathematical propagation model will be given.

Keywords: Turbine, RF Propagation, EM Measurements

1. Introduction

As part of a wireless strain gage project, a series of experimental measurements were made of propagation in real full-scale jet engine turbines. Propagation in engine turbines previously has considered the turbine as an open ended cavity [1, 2, and 3]. This model does not include the complex stator and rotor blade distribution and the non-uniform cross section of the air passage as the air is compressed from stage to stage. In this study, these theoretical limitations are overcome by a direct experimental measurement program. Experimental transmission measurements were made from the inlet to the outlet, from the outlet to the inlet, and from the outlet to several inspection boreholes in the engines. Reflection measurements were also made, and reflections from the various stages of the turbine can be identified in the time domain plots of the data.

We also created a simplified model of the internal propagation in order to understand the multipath environment. Parameters from the experimental measurements can be used to set the parameters of the scattering model.

We will show the measurement data in both the frequency domain and the time domain. We will show the model, and comparisons between the model results and the measurement results. Overall propagation characteristics will be summarized.

2. Experimental Setup

Both a small turbine (F110-GE-100; F16) and a large turbine (GE CF6-50; Boeing 747) were tested. Figure 1 shows a cut-away diagram of the large turbine (typical of Jet engine turbines). Air flows into the large blade (fan) section, where some air is diverted in a bypass chamber outside of the working air. The compressor section (between the inner shaft and the outer compressor wall) is the region of RF propagation of interest here. Air is compressed in stages between stator (non-rotating) blades and rotor blades. The size of the air gaps (and thus of the RF propagation duct) decreases from the inlet to the final compressor stage.

Propagation was measured by using a network analyzer and UWB ridge waveguide horn antennas (2-12 GHz). Identical antennas were used to transmit and receive the signal, or a small conical monopole was inserted into the boreholes as a receive antenna. Scattering measurements (S_{11}) were also made.

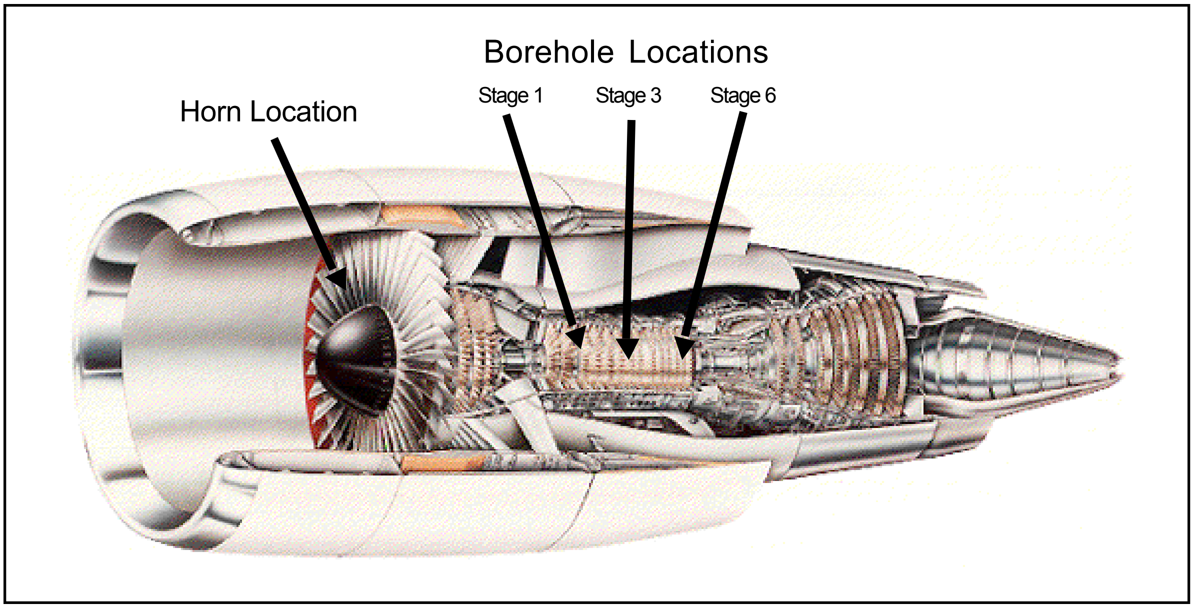

Figure 1. Large Turbine used for testing (GE CF-6-50; Boeing 747)

3. Experimental Results

Example propagation data for the F110 turbine is plotted in figure 2 (circumferential polarization) and figure 3 (radial polarization). In these figure we show received signal as a function of frequency as the rotor blades are turned in small increments. Also included is a reference curve of cable propagation made by simply connecting the two cables together with an adapter.

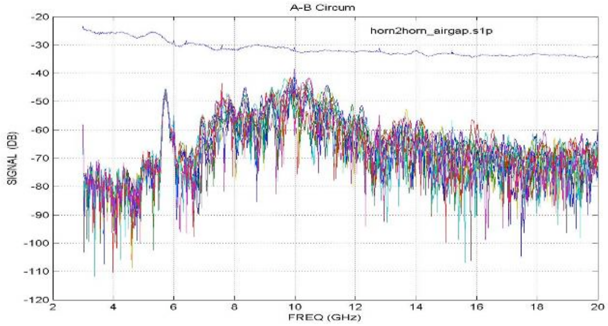

Figure 2. Amp. (dB) vs. Freq.; F110 Outlet to Inlet; Circumf. Polarization; Various Blade Rotation Angles

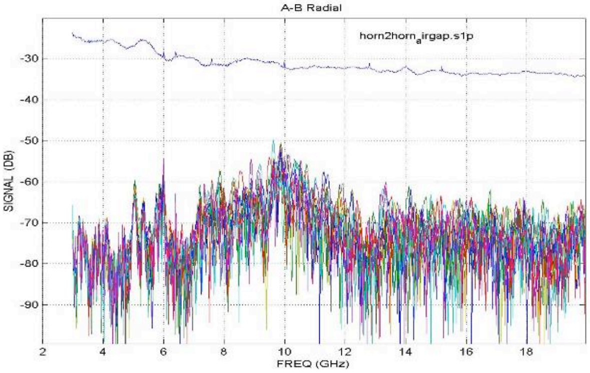

Figure 3. Amp. (dB) vs. Freq.; F110 Outlet to Inlet; Radial Polarization; Various Blade Rotation Angles

The F110 propagation data from figure 3 was then transformed to the time domain (IFFT) and plotted in figure 4. (Radial polarization results are very similar.) Note the ring-down time of approximately 17 ns. This demonstrates the character of the multiple internal reflections that occur in such turbine propagation. This decay time is still at least a factor of ~1,000 times faster than the blade periodic rate even for turbine rates of 20,000 rpm. Thus it can be seen that the blade periodic characteristic can be studied using microwave probing even in the presence of this multiple internal reflection environment.

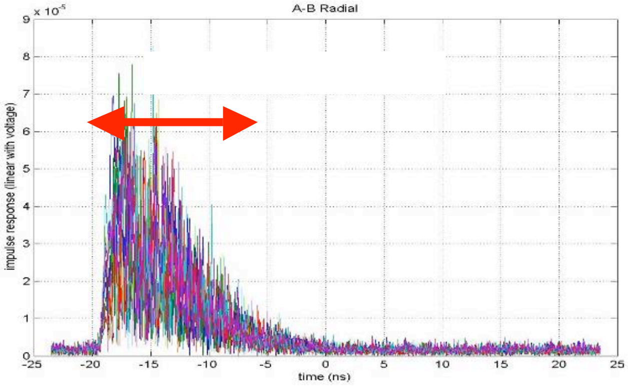

Figure 4. Amp. (dB) vs. Time (ns); F110; Outlet To Inlet; Radial Polarization; Various Blade Rotation Angles.

4. Propagation Model

A propagation model was also created to study the multipath induced modulation. This was needed to permit the development of algorithms for extracting internal sensor data from a rotating turbine. It was important to understand the effect of these multipath terms on modulated sensor data. A sketch of the model is shown in figure 5. A transmit point is defined on a stationary location near the engine inlet or outlet. Signals propagate from this source point to a point on a rotating blade after reflecting from various rotating (rotor) and stationary (stator) blades. The internal scattering magnitude and polarization values are derived from the measurement data and input as parametric descriptions of the various internal reflection terms.

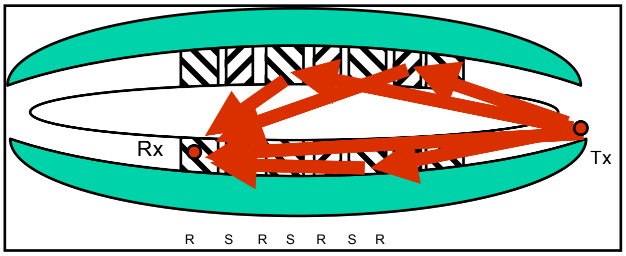

Figure 5. Propagation Model

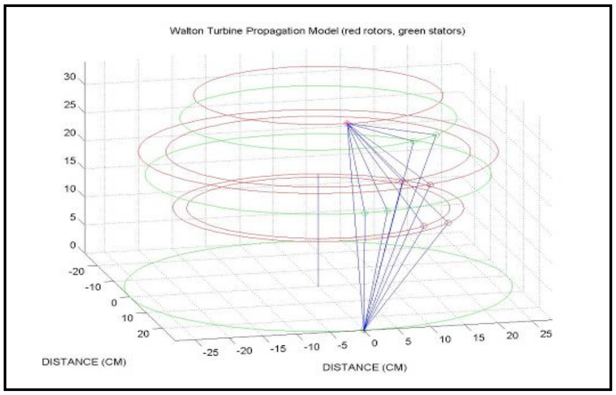

Figure 6. Example of a Set of Propagation Paths.

A simplified example of the initial ray paths taken from this model is shown in figure 6. This figure shows a direct path and a set of internal reflected paths for the propagation. (It is simplified for the purpose of this illustration.) The resulting propagation data for various blade rotation angles is shown in figure 7. Note that the variability as a function of frequency and blade rotation angle is similar to that of the experimental test data.

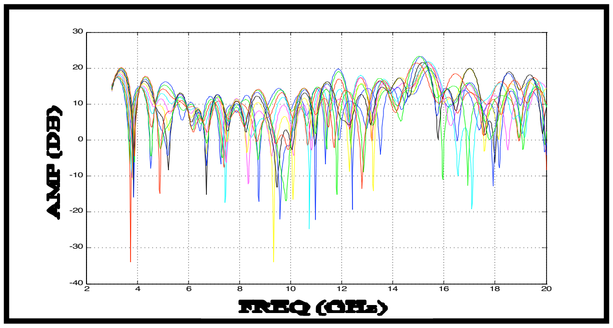

Figure 7. Example Results from the Model Data for Various Blade Rotation Angles (1-way prop.; 20 stators, 20 rotors).

5. Rotation Independent Windows

Careful observation of figures 2 and 3 reveal that there are some frequency bands near 5.6 GHz where the propagation is not effected by the rotation angle of the turbine blades. These frequency bands can be considered "window" bands where a sensor module attached to a turbine blade may transmit sensor information (strain temperature, acoustic, etc) data with little blade-induced modulation. A more detailed search for such "window" band can be done as is shown in figure 8. In this figure, the propagation magnitude as a function of frequency and blade angle is shown. Note the horizontal bands of constant color where there is little blade-induced modulation. Further studies of this type should reveal the detailed characteristics of these special bands so that they may be exploited in the future as FR sensor bands.

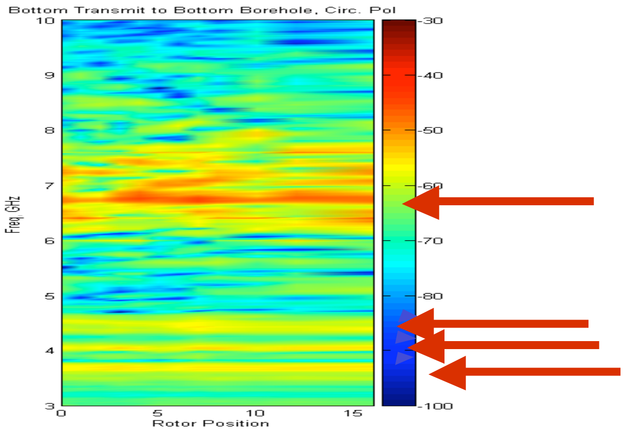

Figure 8. Amp. (dB) vs. Freq. and Rotation; F110-GE-100 (Boeing 747) Propagation to Farthest Borehole (Circumf. Polariz) vs. Freq. and Rotor Position. (The Arrows Point to "Window" Bands)

6. Conclusions

We have shown experimental and modeling data for propagation in large jet engine turbines. Internal propagation was shown to be only 10 to 20 dB below propagation in free space over the same distance. Propagation multipath is shown to involve a large number of multiple reflections, and the excess delay times have been shown to be approximately 17 ns for a Boeing 747 engine. In most frequency bands, the moving turbine blades have a 10 to 15 dB modulation effect on the internal propagation, but we have shown that there are often some special frequency bands ("window bands") where the blade rotation has little or no effect on the amplitude of the propagation.

We plan to continue the study of these internal propagation modes and especially the window bands for the purpose of communicating with small wireless sensors mounted on the rotating blades.

7. References

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