An Ultra-Wideband Absorber Backed Planar Slot Antenna

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Abstract **─** Planar antenna designs have many advantages such as low-profile, light-weight, and ease of fabrication and integration. Here, a planar slot antenna implemented on ceramic substrate with coplanar waveguide feed is considered. With absorber loading the design provides 50 Ω input impedance over the frequency range 0.3–3 GHz so it is considered ultra-wideband. This paper summarizes a numerical investigation using both frequency and time-domain solvers. The results serve to guide the future analysis of broadband antennas with lossy dielectric loading for ground penetrating radars. The evaluation of radar performance requires further simulation and model validation based on antenna measurements.

Index Terms **─** Ground Penetrating Radar, Method of Moments, microwave absorber, planar slot antenna, Time-Domain Finite-Difference.

I. INTRODUCTION

This paper investigates the numerical analysis of a planar slot antenna in the time- and frequency-domains using commercial solvers. FEKO (www.feko.info) is used for the frequency-domain solver while the GEMS Simulator (www.2comu.com) is used for the transient response. In free space the time-domain solver can be more efficient, but when calculating field penetration into the soil the problem space increases substantially. In addition, the time domain solver can have limitations or reduced accuracy when loading the antenna with high loss materials.

Planar slot antennas can have input impedance near 50 Ω over a broad bandwidth (BW) without additional impedance matching [1]. A metal reflector can also be used to increase directivity, but introduces gain variations as a function of frequency. For handheld ground penetrating radar (GPR) applications, the embodiment considered here is restricted in size to a 3-inch (76.2 mm) cube. A model was constructed using FEKO to modify the baseline shape resulting in an antenna size 75 mm (W) x 72 mm (L) with SMA edge connector.

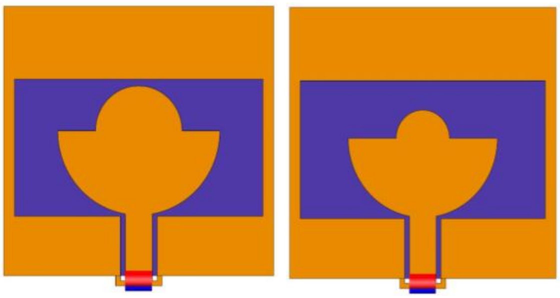
II. ANTENNA DESIGN

The antenna is a coplanar waveguide (CPW) fed patch radiator exciting a rectangular slot. A broad frequency BW slot can be obtained by careful design of the structure exciting the slot and tapering the slot corners. A common implementation was presented in [2] shown in Fig. 1 (a), but the provided model parameters were not consistent with the fabricated antenna. Some parameters were modified resulting in the antenna model in Fig. 1 (b). The CPW line appears to be designed for a larger permittivity than described in [2]. The revised antenna size was increased by a factor of three and modified to improve the low frequency bandwidth as shown in Fig. 1 (c) with the prototype shown in Fig. 1 (d). The planar slot antenna with coaxial end-launch connector is modeled with a thin wire or an edge port. The CPW feed was adjusted to be on TMM10 having $\varepsilon_r = 9.2$ and $\tan\delta = 0.0022$ [3] with thickness 0.787 mm (31-mils). An edge port was used with FEKO as can be seen in Fig. 1, while GEMS used the same feed structure with a wire port to represent the SMA connector. Multiple CPUs were used with the required CPU times and RAM adjusted to be for a single processor and for symmetry when used. With this linear scaling GEMS required 1.53 CPU hours (0.22 GB RAM), while FEKO took 10.6 CPU hours (0.52 GB RAM) for 151 frequencies. The GEMS runtime was much shorter but only 27 far field patterns were calculated (requiring 7.7 min). In general, the time domain solver is more efficient for UWB antennas and the impedance transformed to the frequency domain can be done for an arbitrary number of frequencies.

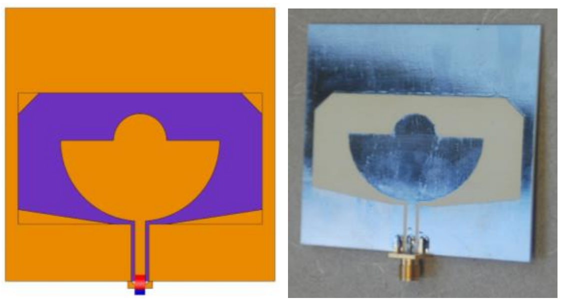
This planar slot was simulated with FEKO and GEMS over the frequency range 0.3–3 GHz with the S_{11} comparison shown in Fig. 2 (a). The FEKO and GEMS results have similar frequency dependence and fair agreement in amplitude, but neither fully captures the measured impedance variations. GEMS obtains the measured low-frequency behavior but without absorber loading the antenna is not well matched. Adaptive or fine meshing was used in both codes and the GEMS residual signal converges to a level 54 dB below peak. Compared to the measured data, GEMS obtains an artificial result near 2.5 GHz, which is the largest error in return loss obtained with the time-domain solver (15 dB), while FEKO has a 3 dB discrepancy near 2.7 GHz.

Submitted On: February 9, 2015
Accepted On: January 16, 2016

Over the required BW the radiation pattern is stable becoming multi-lobed above about 3 GHz. However, the E-plane pattern tilts forward near 3 GHz as can be seen in Fig. 2 (b) where the realized gain at zenith is reduced at high frequency owing to a tilted main lobe. The measured boresight gain indicates a more tilted pattern shape. The oscillations observed in the measured gain are artifacts of the anechoic chamber being noise limited at certain frequencies.

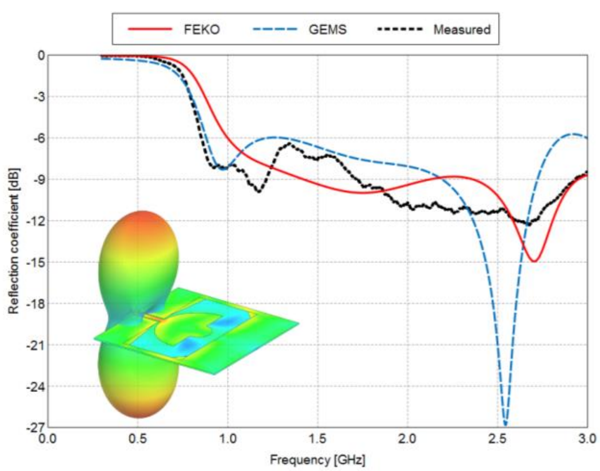


(a) (b)

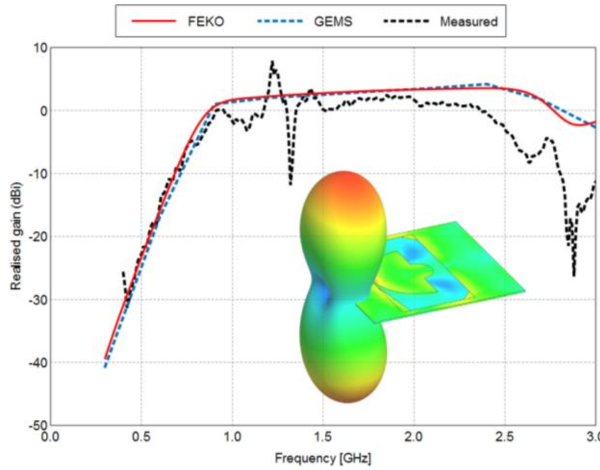


(c) (d)

Fig. 1. Planar slot antennas: (a) original design [2], (b) modified version, (c) proposed design, and (d) fabricated antenna.



(a)



(b)

Fig. 2. Planar slot antenna on TMM10 substrate: (a) return loss and (b) realized gain vs. frequency.

III. ABSORBER LOADING

This structure has a larger impedance BW and higher gain compared to the radiator only as a planar monopole antenna. At low frequencies the antenna has the radiation pattern of a dipole with the electric (E-) field being parallel to the CPW feed. This antenna is loaded with a lossy dielectric 2.5-inch thick to extend the impedance BW to lower frequencies at the expense of antenna efficiency. A 3-layer graded microwave absorber, such as AN74 [4] is used with or without metal backing. The high loss layer ($\varepsilon_r = 3$ and $\tan\delta = 2$) is next to the antenna with the middle and last layers having less loss at $\varepsilon_r = 1.5$ and $\tan\delta = 0.5$ and $\varepsilon_r = 1.4$ and $\tan\delta = 0.45$, respectively. This 3-layer absorber is simulated in GEMS using $\varepsilon_r = 3$ with conductivity $\sigma = 0.24$ S/m with the same parameters used in FEKO for comparison. At low frequency both representations are similar and consistent with measured data. But as can be seen in Fig. 3, the graded absorber better represents the measured return loss above 1.5 GHz. The results indicate that for GPR applications the antenna is poorly matched at low frequency. The antenna transient excitation and radiated field indicate some late time ringing which can be mitigated by absorber loading. This loading requires a tradeoff between impedance matching at low frequencies and antenna efficiency and should be measured to determine adequate radar performance. Ground penetrating radars typically operate over a decade impedance BW with antennas in close proximity to the soil. Thus, the absorber loading and slightly tilted main beam may not hinder performance for this application.

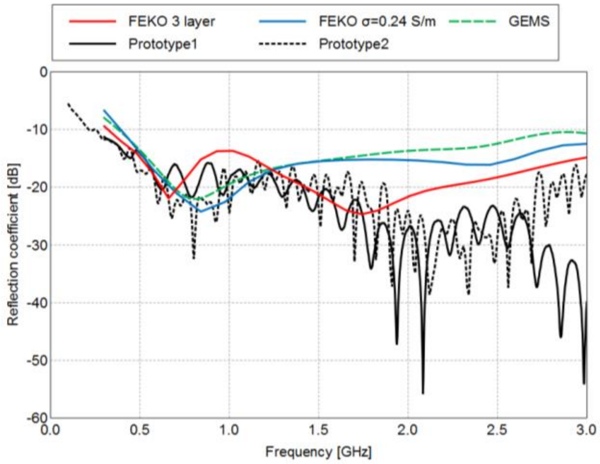


Fig. 3. Planar slot antenna on TMM10 substrate return loss with microwave absorber.

The gain at zenith vs. frequency is shown in Fig. 4 without metal backing for constant conductivity, σ = 0.24 S/m. The results indicate that the absorber parameters vs. frequency are not known exactly and should be measured. The simulation results are in good agreement but the measured gain is less than predicted indicating higher loss than assumed. The results with absorber and metal backing are shown in Fig. 5 where the metal backing introduces gain variations with frequency. The design requires a tradeoff between impedance matching at low frequencies and antenna efficiency. A customized absorber with known frequency dependence may be required to optimize performance with this antenna.

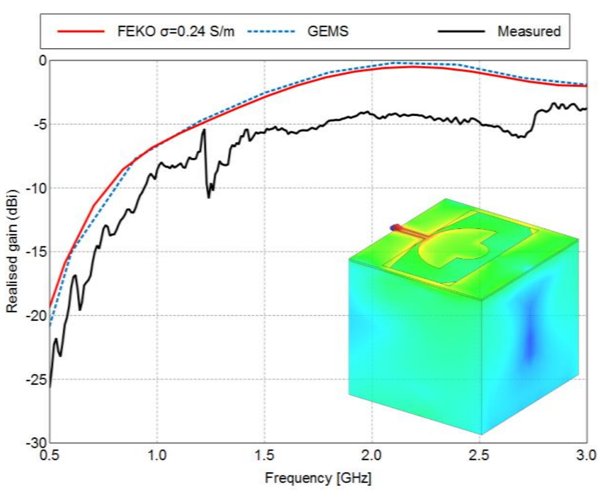


Fig. 4. Absorber loaded planar slot antenna realized gain on boresight vs. frequency.

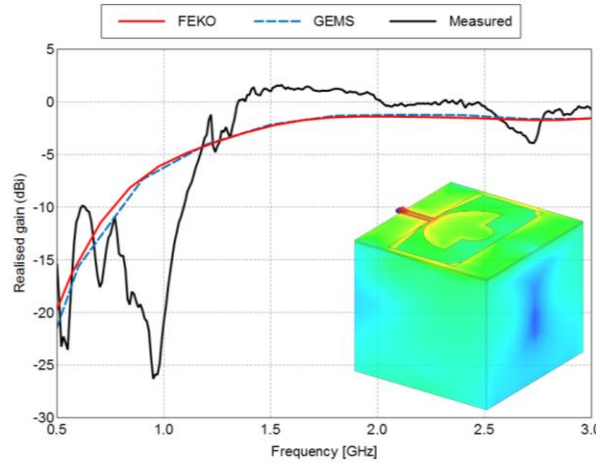


Fig. 5. Absorber loaded slot antenna with metal backing realized gain on boresight vs. frequency.

IV. CONCLUSION

The UWB antenna is a critical component for GPR systems and should radiate a sharp pulse with low reverberation (ring down) from multiple reflections over the antenna structure [5]. The design objective is complicated by physically (and electrically) small antenna requirements for hand-held systems. Both time and frequency domain codes produce similar results indicating that this antenna would require lossy dielectric loading to avoid ringing from the edges. This is common practice to sacrifice antenna efficiency for broad impedance BW and flat gain response over the required frequency band. Although some of the measured gain variations are artificial, a frequency dependent absorber will be used in future simulations to better capture the measured frequency dependence.

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