Full Characterization of Directive and Non-Directive Surface-Wave Launchers and Application to Surface-Wave and Leaky-Wave Beam Scanning Antennas

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Abstract

This work investigates types of slot configurations suitable for surface-wave (SW) launching on a grounded dielectric slab (GDS). Such ground plane slots act as Yagi-Uda like surface-wave launcher (SWL) antennas that can excite a bound TM_0 SW mode at millimeter wave frequencies. Two types of SWL antennas that generate bidirectional and unidirectional SW beam patterns on the guiding surface are investigated. Measurement and simulation results illustrate the SW beam patterns generated by these SWLs. In addition, an array of SWLs will be investigated for single frequency SW beam steering on the GDS and extension to leaky-wave excitation.

1. Introduction

Recently planar Yagi-Uda like slot configurations have been recognized as a practical feeding technique for launching bound surface-waves (SWs) onto high permittivity substrates. In these designs, a cylindrical TM_0 SW mode is excited on a grounded dielectric slab (GDS) and propagation occurs along the air dielectric interface. Such surface-wave launchers (SWLs) are applicable to millimeter wave power distribution networks and leaky-wave (LW) beam scanning antennas [1]-[6].

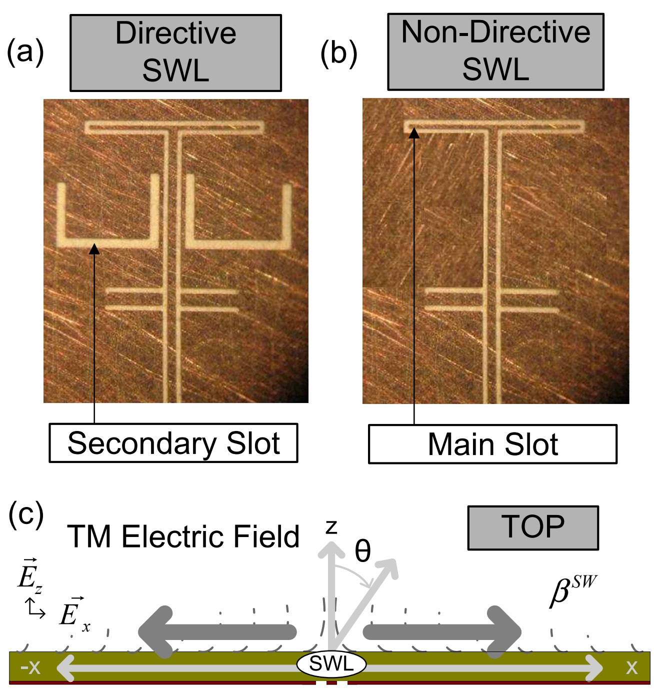

Figure 1: Directive and non-directive SWLs considered in this work. (a) Directive SWL slot configuration described by a main radiating driven slot and secondary reflector slots. (b) Non-Directive SWL slot configuration depicted by only a single SW radiating slot. (c) Bound TM_0 SW field distribution in the forward $(+\hat{x})$ and backward $(-\hat{x})$ directions.

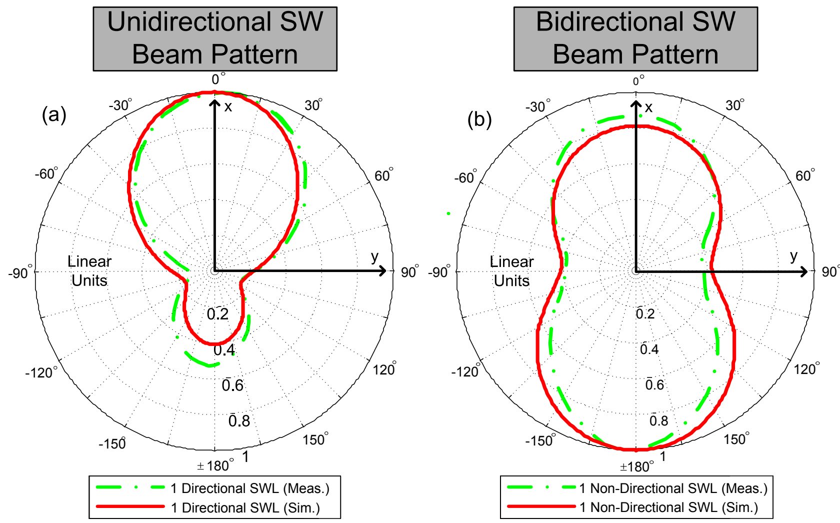

Figure 2: Measured and simulated SW beam patterns for the directive and non-directive SWLs (normalized and shown in linear units). (a) The directive SWL generated a SW mainly in the forward $+\hat{x}$ direction. (b) The non-directive SWL generated a SW in both the $\pm\hat{x}$ directions.

Recent characterizations of specific slot configurations are reported. Two types of SWL antennas (placed at the center of a GDS) are investigated that generate unidirectional and bidirectional SW field distributions on the guiding surface. Specifically, a unidirectional SW can be produced by a directive SWL where the majority of the SW field distribution is directed in the forward $(+\hat{x})$ direction. Conversely, bidirectional SWs can be driven by non-directive SWLs where SWs are directed in both the forward $(+\hat{x})$ and backward $(-\hat{x})$ directions. Measurement and simulation results are provided illustrating the field distributions and hence SW beam patterns generated by these directive and non-directive SWLs.

2. Directive and Non-Directive Surface-Wave Launcher Operation

To excite the dominant TM_0 SW mode on the GDS, a coplanar waveguide (CPW) transmission line (TL) was utilized to feed the directive and non-directive SWLs. Such half wavelength slots in the ground plane have field distributions which can inductively couple to the dominant TM_0 SW mode of the GDS. The substrate properties ($\epsilon_r = 10.2$, $h = 1.27$ mm and $\tan\delta = 0.0023$) were properly chosen such that more than 85% of the input power was coupled into the dominant SW mode of the slab [3]. Physically, the directive SWL is described by a main radiating driven slot with secondary reflector slots as shown in Fig. 1 (a). The fields from the main radiating slot constructively interfere in front and destructively in the back of the SWL, increasing the forward radiated SW power and thus achieving unidirectional propagation. The non-directive SWL of Fig. 1 (b) does not have these secondary slots, and as expected SWs are generated in both the backward and forward directions achieving bidirectional SW propagation as illustrated in Fig. 1 (c).

3. Unidirectional and Bidirectional Surface-Wave Beam Patterns

To characterize the unidirectional and bidirectional SW field distributions measurements were performed and compared against simulated values. The results in Fig. 2 illustrate the unidirectional and bidirectional SW beam patterns for the directive and non-directive SWLs. The directive SWL generates a SW mainly in the forward $+\hat{x}$ direction defining a unidirectional beam pattern. Conversely, the non-directive SWL produces a SW in both the $\pm\hat{x}$ directions, with what appears to be more power in the backward region.

The experimental setup used to measure the SW beam patterns is shown in Fig. 3. Each SWL was placed at the center of a large GDS and fed by a CPW TL. The magnitude of the electric field was sampled 0.5 mm away from the GDS (top) and on the edge of a circle (with radius $r_0 = 4.5$ cm) centered at the main radiating slot. The fields along this circle represent the SW field distributions in the far field region ($r_0 >> \lambda^{SW}$) and thus the

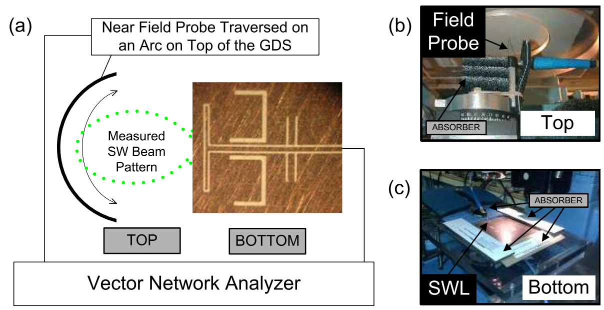

Figure 3: Surface-wave beam pattern measurement system. (a) A near field probe (on top of the GDS) was used to measure the SW field distribution along the edge of a circle on the guiding surface. The system was connected to a vector network analyzer for measurement recording. (b) The probe was mounted on a modified rotation stage and SW beam pattern was measured (on top of the GDS). (c) The SWL was excited (on the bottom) and absorber was used to minimize reflections.

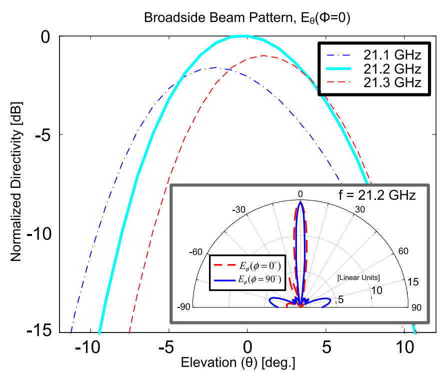

Figure 4: $E_\theta(\theta, f)$ beam pattern normalized to maximum at 21.2 GHz for the broadside radiating LWA using only a single directive SWL (shown in dB and a polar plot in linear units at 21.2 GHz only).

SW beam pattern on the GDS. Furthermore, results were processed using aperture gating (to eliminate multiple reflections and unwanted image sources) and time gating (to minimize high frequency noise, multiple reflections due to cable bending and field probe discontinuities from VNA measurements) [4].

4. Application to Surface-Wave Beam Scanning and Leaky-Wave Antennas

By utilizing such directive or non-directive SWLs and by the addition of metallic gratings or strips (on top of the GDS) LWs can be excited [2]-[7]. Essentially new boundary conditions exist and the transformation from a bound mode to a radiated mode is realized. The periodic metallic coverings define an effective partially reflecting surface (PRS) and directive cylindrical-sector beam patterns can be generated by this type of 2-D planar leaky-wave antenna (LWA). For instance, the directive SWL could be placed at the edge of a GDS and used to excite a single LW beam pattern in the far field. Simulated results of a broadside radiating LWA using a single directive SWL [6] are shown in Fig. 4. Conversely, using non-directive SWLs two-sided beam patterns can be generated in the far field. The bidirectional SW field distribution propagating on the GDS (realized by a non-directive SWL placed at the center of a GDS covered with a suitable PRS) can also excite bidirectional LWs along the guiding surface.

If the SWLs are placed in a linear array, SW beam scanning is possible as shown in Fig. 5 and the SW field distribution can be steered into different regions on the GDS. By varying the relative phase difference between two SWL elements, $\delta = \Phi_2 - \Phi_1$, the SW beam pattern can be controlled as shown in Figs. 5 (b) and (c) for $\delta = 0^\circ$ and $\delta = 90^\circ$. Furthermore, directive LW beam patterns can also be steered at a single frequency by the addition of a suitable PRS.

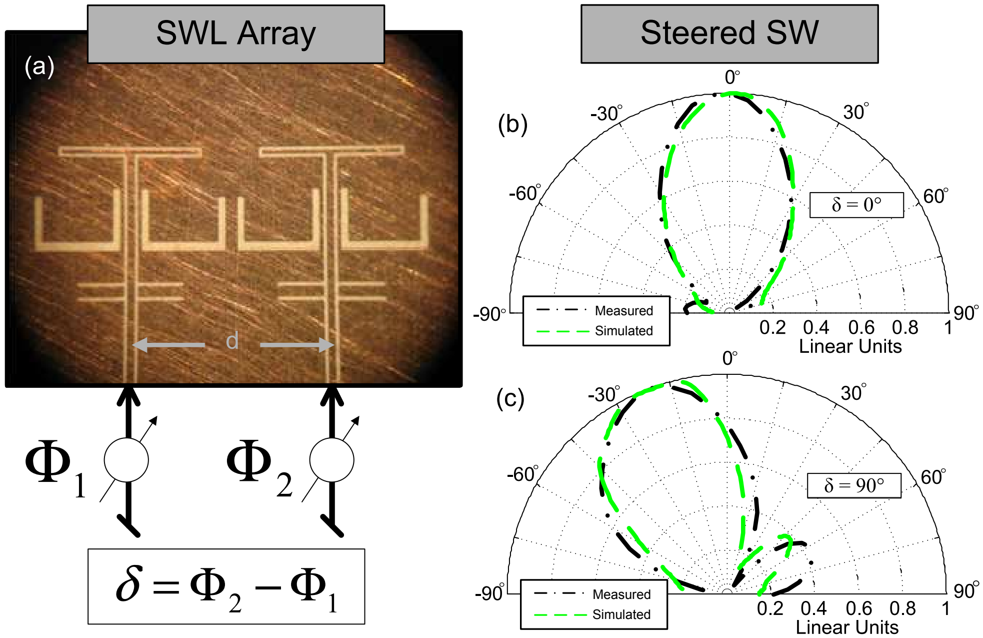

Figure 5: Directive SWLs placed in a two element array for SW beam scanning and extension to single frequency LW beam steering. (a) By variation in δ the SWL array can generate a SW beam pattern that can be steered on the GDS. (b) and (c) Measured and simulated SW beam patterns for $\delta = 0°$ and $\delta = 90°$ (normalized and shown in linear units).

5. Conclusion

Directive and non-directive SWL antennas have been shown to produce unidirectional and bidirectional SW beam patterns on a GDS. With the utilization of a PRS, such SWLs can be used to excite LWs. In addition, an arrayed configuration of SWLs can be applied for single frequency SW, and hence LW, beam steering.

6. References

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