AFRL-SN-WP-TP-2006-125

MICROSTRIP LEAKY WAVE ANTENNA PERFORMANCE ON A CURVED SURFACE (PREPRINT)

Joshua Radcliffe, Gary Thiele, Robert Penno, Steve Schneider, and Leo Kempel

JULY 2006

SENSORS DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7320

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE ***(DD-MM-YY)***
July 2006

2. REPORT TYPE
Conference Paper Preprint

3. DATES COVERED ***(From - To)***
05/01/2004 – 05/01/2006

4. TITLE AND SUBTITLE
MICROSTRIP LEAKY WAVE ANTENNA PERFORMANCE ON A CURVED SURFACE (PREPRINT)

5a. CONTRACT NUMBER
In-house

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
Joshua Radcliffe, Gary Thiele, and Robert Penno (AFRL/SNDR)
Steve Schneider (AFRL/SNS)
Leo Kempel (Michigan State University)

5d. PROJECT NUMBER
7622

5e. TASK NUMBER
11

5f. WORK UNIT NUMBER
0D

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
RF and EO Subsystems Branch (AFRL/SNRD)
Aerospace Components & Subsystems Technology Division
Sensors Directorate
Air Force Research Laboratory, Air Force Materiel Command
Wright-Patterson Air Force Base, OH 45433-7320

Signature Branch (AFRL/SNS)
WPAFB, OH 45433-7320

Michigan State University
2120 Engineering Building
East Lansing, MI 48824-1226

8. PERFORMING ORGANIZATION REPORT NUMBER
AFRL-SN-WP-TP-2006-125

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Sensors Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright-Patterson Air Force Base, OH 45433-7320

10. SPONSORING/MONITORING AGENCY ACRONYM(S)
AFRL-SN-WP

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFRL-SN-WP-TP-2006-125

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
PAO Case Number: AFRL/WSC 06-0143, 17 Jan 2006.

This conference paper preprint contains color and has been submitted for publication in the Proceedings of the 2006 IEEE Antennas and Propagation Society International Symposium and URSI National Radio Science Meeting (IEEE AP/S URSI). One or more of the authors is a U.S. Government employee working within the scope of their Government job; therefore, the U.S. Government is joint owner of the work. If published, the publisher may assert copyright. The Government has the right to copy, distribute, and use the work. All other rights are reserved by the copyright owner.

14. ABSTRACT
Microstrip antennas are popular due to their ease of construction and minimal dimensions; especially in terms of thickness. These antennas typically are resonant structures and hence having a relatively small operational bandwidth. An alternative microstrip structure that maintains the advantage of a thin structure at the expense of a larger lateral dimension is a terminated microstrip line. The fundamental microstrip mode does not radiate well; however, the first higher-order mode does. Such antennas are generally referred to as leaky wave antennas.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT:	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON (Monitor)
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Joshua Radcliffe
Unclassified	Unclassified	Unclassified	SAR	10	**19b. TELEPHONE NUMBER** *(Include Area Code)* N/A

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

Microstrip Leaky Wave Antenna Performance on a Curved Surface

Joshua Radcliffe, Gary Thiele, Robert Penno, Steve Schneider
Air Force Research Laboratory, AFRL/SNRR
2241 Avionics Circle, Bldg 620
Wright Patterson AFB, Ohio 45433
joshua.radcliffe@wpafb.af.mil

Leo Kempel
Michigan State University
2120 Engineering Building
East Lansing, MI 48824-1226
kempel@msu.edu

Abstract

Microstrip antennas are popular due to their ease of construction and minimal dimensions; especially in terms of thickness. These antennas typically are resonant structures and hence having a relatively small operational bandwidth. An alternative microstrip structure that maintains the advantage of a thin structure at the expense of a larger lateral dimension is a terminated microstrip line. The fundamental microstrip mode does not radiate well; however, the first higher-order mode does. Such antennas are generally referred to as leaky wave antennas.

One issue with using these antennas is that the driving point impedance is dispersive; hence, fixed port impedance terminations limit the operational bandwidth of the antenna. In addition, the fraction of supplied power delivered to the terminating port is not radiated; hence the efficiency of the antenna is not optimal. In this paper, the effect of curvature on radiation properties of a leaky-wave antenna is investigated through computational modeling and experiment.

1.0 Introduction

One of the "Holy Grails" for conformal antenna engineers is an antenna with wide bandwidth, high efficiency, a convenient radiation pattern, and low profile. These requirements typically are conflicting and an antenna engineer must make trade-offs amongst these requirements. Mircrostrip leaky-wave antennas have both low profile and wide bandwidth features. The thickness of a microstrip leaky-wave antenna is no greater than that of the common patch antenna albeit with substantially more bandwidth. Leaky-wave antennas have been extensively studied by Oliner [0], Menzel [2], Lee [3], and Lin [4-6] among others. The radiating mode for all of these cases is the EH_1 mode, e.g. the first higher-order mode. One of the major issues with operating a microstrip antenna in the first leaky-wave mode involves preferential excitation of that mode (as compared to the fundamental, non-radiating EH_0 mode). Menzel [2] utilized a periodic array of slots to suppress the fundamental mode while Lin *et al.* [4] utilized a more complex two-port feeding structure. All of the antennas examined in these previous papers were full-width leaky wave (FWLW) microstrip antennas.

An alternative is the half-width leaky wave (HWLW) antenna extensively studied by Thiele *et al*. [7-9]. This antenna is formed by placing a shorting ridge, between the microstrip and ground, along one long edge of the antenna. The other long edge will support a magnetic current wall that is responsible for radiation.

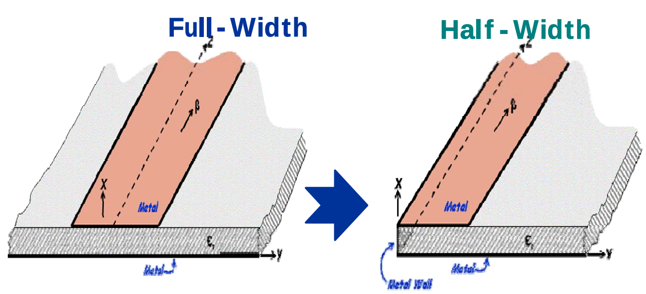

Figure 1: The FWLW antenna (left) and the HWLW antenna (right).

The HWLW antenna by itself has a major advantage over the FWLW antenna, namely a relatively simple feed and loading approach. One of the major challenges of the FWLW antenna is suppression of the EH_0 mode. Clearly, if the antenna is operated at a frequency above the cut-off frequency for both the EH_0 and EH_1 modes, then both modes can be excited. Previous papers have discussed various methods for suppressing the lower-order mode in preference to the leaky-wave mode [2,4-6,11]. For the HWLW antenna, due to the presence of the shorting wall along one long edge, the lower order mode is automatically suppressed. The driving point impedance

PREPRINT

can be approximated using an open waveguide model [6] along with estimated wave numbers using the Transverse Resonance Method [3]. Using this information, both the feed location and the location of a lumped load can be estimated. The purpose of the lumped load is to suppress the backward traveling wave that will exist if no load is used. Kempel *et al.* [9] studied the effects of the loaded HWLW antennas in detail and its effects on the radiated patterns. These results also correlate with FWLW results, both in terms of driving point impedance and patterns.

In this paper, we will present a microstrip leaky wave antenna design on a curved surface. Theoretical and measured pattern results will be shown and compared; the potential exists for this antenna design to show an improved end termination scheme when present on a curved surface.

2.0 Leaky Wave Antenna Theory

A leaky wave antenna is a special form of traveling wave antenna characterized by a wave propagating interior to a guiding structure rather than exterior as in the case of a Beverage antenna. As seen in Figure 2, the dominant mode of a standard microstrip line does not radiate since the guided wave underneath the microstrip is coherent (hence the popularity of microstrip transmission lines). However, when the dominant mode is suppressed, the first higher order mode undergoes a phase reversal of the electric field along a centered vertical axis, as shown in Figure 3, and radiation of the first higher order mode occurs.

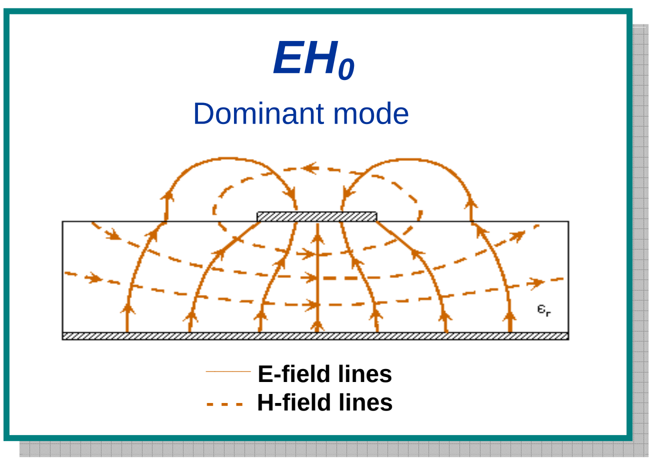

Figure 2: The electric field distribution of the dominant mode (does not radiate).

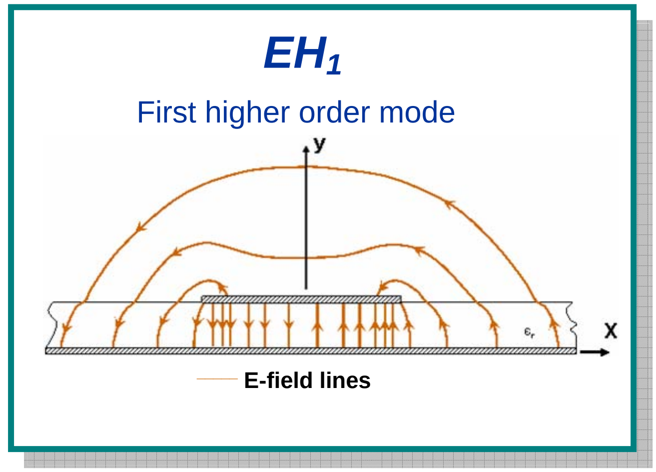

Figure 3: The electric field distribution of the EH_1 mode.

This guided-wave energy sets up a leaky wave exterior to the guiding structure and "leaks or sheds" power away from the guiding structure in a controlled way as the mode propagates from the feed to the termination. In doing so, radiation occurs with a peak that squints in the direction of propagation, as is the case with a Beverage antenna; however, this configuration is amenable to conformal installation.

As aforementioned, Kempel *et al.* [9] studied the effects of loaded end terminations on the backward traveling wave present in LW antenna structures. They found that the presence of a proper load diminishes the backward traveling wave significantly; this research stresses the importance of proper end terminations, allowing the maximum amount of energy to leak off of the antenna.

The current on either wall can be represented as

$$\mathbf{M}(x,y,z) = \pm\hat{z}A_{\pm}e^{-\left(\frac{\alpha(z,f)}{k_0}\right)k_0 z}e^{-j\left(\frac{\beta(z,f)}{k_0}\right)k_0 z} \tag{1}$$

where the attenuation term $\alpha(z,f)$ and the propagation term $\beta(z,f)$ are in general a function of both position and frequency, k_0 is the free-space wavenumber, and the wave coefficients $(A_{\pm})$ are associated with the two magnetic wall currents at $x = \pm w/2$ where w is the width of the full-width microstrip. The attenuation and propagation terms for an axially invariant structure can be determined using the Transverse Resonance Method (TRM) [3]. Once the propagation parameters are known, the driving point impedance for a semi-infinite line can be estimated using an open waveguide model, viz. [5-6][1] as

$$Z_w = 8Z_0 \sin^2\left(\frac{\pi y}{w_{eff}}\right)\frac{k_0 h}{k w_{eff}}\sqrt{\frac{\mu_r}{\varepsilon_r}} \tag{2}$$

The input impedance for a finite, loaded leaky-wave antenna can be estimated using the impedance transformation

$$Z_{in} = Z_w\left[\frac{Z_L + Z_w \tanh(\gamma L)}{Z_w + Z_L \tanh(\gamma L)}\right] \tag{3}$$

where Z_L is the load impedance (for this paper, $Z_L = 50\Omega$) and $\gamma = jk = j(\beta - j\alpha)$.

In (2), the effective microstrip width is given by Wheeler's approximation [12]

$$w_{eff} = h\left\{\frac{w}{h} + \frac{2}{\pi}\ln\left[2\pi e\left(\frac{w}{2h} + 0.92\right)\right]\right\} \tag{4}$$

Use of (2)-(4), with the propagation parameters provided by TRM, allows determination of the appropriate feed and load locations along the width of the strip.

Example: Leaky-wave Antenna on Duroid

As an example, consider a leaky-wave antenna printed on Duroid 5870 (31 mils thick, $\varepsilon_r = 2.33$, $\tan\delta = 0.0005$). The full-width strip width is 8.32 mm tapering to 5.98 mm. The strip is 190 mm long for the simulations and measurements. The antenna is fed with two microstrip lines, excited with opposite phase, as shown in Figure 5. As is clear from (2), the feed locations (at the edge of the full-width antenna) are high impedance points; hence, the need for a quarter-wave transformer. This was designed for 14 GHz operation. Note that no end termination is used and accordingly, a significant attenuation is necessary to avoid a large backward-wave lobe. The strip width tapering is used to control the direction of the main lobe as the antenna is excited at different frequencies within its operational bandwidth.

3.0 Leaky Wave on a Curved Surface

A dual port tapered LW antenna design on a curved surface was modeled in CST Microwave Studio to study the effects of LW antennas in a curved geometry. This antenna is shown in Figure 4.

[1] There is a typographical error in the expression in [6] where the sine function should be squared as shown in (2). The expression is correct in [5].

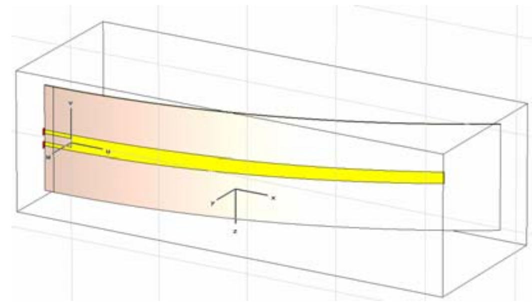

Figure 4: The model of a LW antenna on a curved surface.

The above antenna was designed for a specific value of α and β as described in the previous section at a frequency of 14 GHz. This tapered width design and the subsequent varying propagation constant allowed for a desired change in the leakage constant, α. As the width decreased towards the end of the microstrip, the leakage constant increases and leaves a very small amount of energy left to reflect as a backward traveling wave. The curved surface was modeled attached azimuthally to a cylinder with a radius of 40.64 cm. The computed results from CST Microwave Studio are shown in Figure 5.

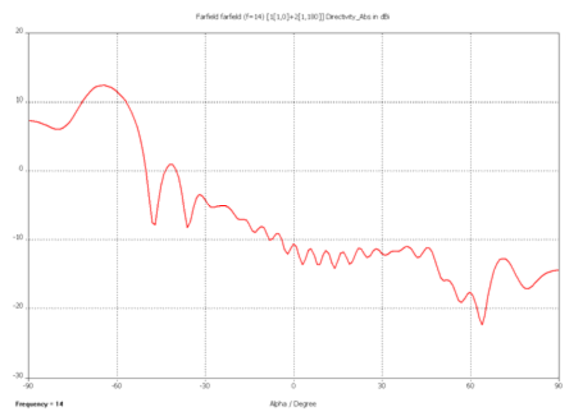

Figure 5: Theoretical E-plane radiation pattern of a LW antenna on a curved surface at 14 GHz.

Figure 6 displays the 3-D radiated far-field pattern of the LW antenna as modeled in CST Microwave Studio. The antenna is noted by the curved black line in this figure.

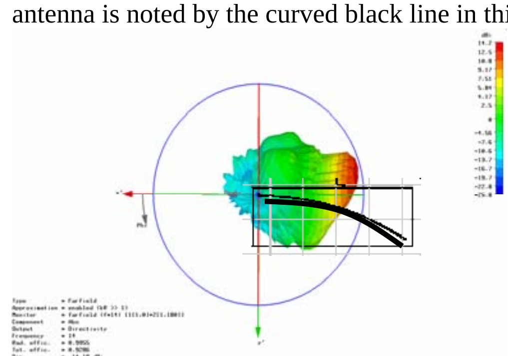

Figure 6: Three-dimensional radiation pattern of a LW antenna on a curved surface.

From the theoretical results, one can notice a few lucid features. One, the beam produced is a near end-fire beam. The reflected wave is not present in the far-field patterns above and is therefore observed to be very small inferring that the majority of the energy is leaked away from the antenna upon reaching the antenna termination.

To check these observations, measurements were performed in AFRL's Radiation and Scattering Compact Antenna Laboratory (RASCAL) at WPAFB, Ohio. The dual port tapered LW antenna was modeled, built and setup within the RASCAL compact range on a PVC pipe of 40.64 cm diameter to match the simulation. The antenna was then measured for over 180 degrees azimuth at the designed frequency of 14 GHz. The measured results obtained from the compact range measurements in RASCAL lined up very well to the theoretical results obtained from a simple radiation model developed in MATLAB and results from CST Microwave Studio as shown in Figure 8.

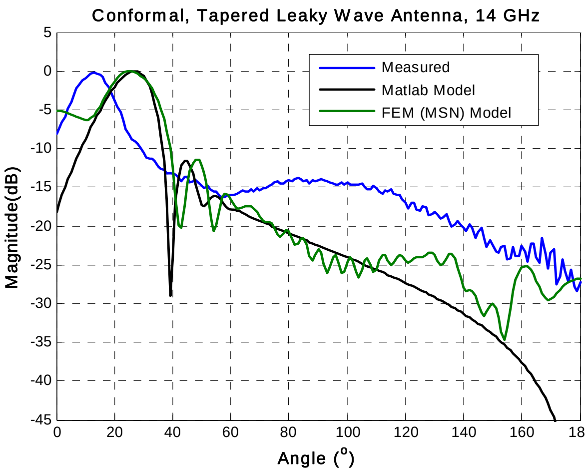

Figure 8: Comparison of theoretical and measured results.

Both theoretical and measured results show the dissipation of the backward traveling wave demonstrating the effectiveness of the curved surface as a practical way to effectively terminate a LW antenna. The significant difference in the measured pattern from the theoretical patterns is the shifting of the main lobe in azimuth approximately 20 degrees.

4.0 Conclusions

Microstrip leaky-wave antennas offer an attractive alternative to traditional resonant microstrip antennas particularly, in terms of the operational bandwidth that can be achieved. Radiative shedding of the supplied power can be enhanced by mounting a leaky-wave antenna on a curved surface as demonstrated both numerically and by measurements.

References

1. A. Oliner, "Leakage from Higher Modes on Microstrip Line with Applications to Antennas", *Radio Science*, 22, pp. 907-912, Nov. 1987.
2. W. Menzel, "A New Traveling-Wave Antenna in Microstrip", *Archiv fur Elektronik und Ubertragungstechnik (AEU)*, Band 33, Heft 4:137-140, April 1979.
3. K.S. Lee, "Microstrip Line Leaky Wave Antenna", Ph.D. Dissertation, Polytechnic University, June 1986.
4. Y-D Lin, J-W Sheen, and C-K. C. Tzuang, "Analysis and design of feeding structures for microstrip leaky wave antennas," *IEEE Trans. Microwave Theory Tech.*, 44, pp. 1540-1547, Sept. 1996.
5. J-W Sheen, W. Hong, and Y-D Lin, "Wide band tapered microstrip leaky-wave antenna," *Proc. 30th European Microwave Conf.*, 2, pp. 234-237, 2000.
6. W. Hong, T-L Chen, C-Y Chang, J-W Sheen, and Y-D Lin, "Broadband tapered microstrip leaky-wave antenna," *IEEE Trans. Antennas Propagat.*, 51, pp. 1922-1928, Aug. 2003.
7. J.S. Radcliffe, G.A. Theile, and G. Zelinski, "A microstrip leaky wave antenna and its properties," *26th AMTA Symp.*, St. Mountain, GA, Oct. 2004.
8. G.M. Zelinski, M.L. Hastriter, M.J. Havrilla, J.S. Radcliffe, A.J. Terzuoli, and G.A. Thiele, "FDTD analysis of a new leaky traveling wave antenna," *2005 IEEE/ACES Intl. Conf.*, Honolulu, Hawaii, Apr. 2005.
9. L. Kempel, S. Schneider, T. Kastle, and G. Theile, "Comparison of two termination schemed for a half-width leaky-wave antenna," URSI National Radio Science Mtg., Washington DC, July 2005.
10. P. Baccarelli, P. Burghignoli, F. Frezza, A. Alli, and P. Lampariello, "The nature of the end-of-scanning region in printed-circuit arrays of leaky-wave antennas," *IEEE Ant. Wirless Propagat. Ltrs.*, 1, pp. 60-63, 2002.
11. P. Baccarelli, P. Burghignoli, F. Frezza, A. Alli, and P. Lampariello, "Novel modal properties and relevant scanning behaviors of phased arrays of microstrip leaky-wave antennas," *IEEE Trans. Antennas Propagat.*, 51, pp. 3228-3238, Dec. 2003.
12. H.A. Wheeler, "Transmission line properties of parallel strips separated by a dielectric sheet," *IEEE Trans. Microwave Theory Tech.*, 13, pp. 172-185, 1965.