AFRL-SN-WP-TP-2006-122

TERMINATION OF A HALF-WIDTH LEAKY-WAVE ANTENNA (PREPRINT)

Daniel Killips, Michael Corwin, Leo Kempel,
and Stephen Schneider

JULY 2006

Approved for public release; distribution is unlimited.

STINFO COPY

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
TERMINATION OF A HALF-WIDTH LEAKY-WAVE ANTENNA (PREPRINT)

5a. CONTRACT NUMBER
In-house

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
Daniel Killips and Leo Kempel (Michigan State University)
Michael Corwin and Stephen Schneider (AFRL/SNDR)

5d. PROJECT NUMBER
7622

5e. TASK NUMBER
11

5f. WORK UNIT NUMBER
0D

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Michigan State University
Department of Electrical and
Computer Engineering
East Lansing, MI 48824-1226

RF and EO Subsystems Branch (AFRL/SNDR)
Aerospace Components & Subsystems Technology Division
Sensors Directorate
Air Force Research Laboratory, Air Force Materiel Command
Wright-Patterson Air Force Base, OH 45433-7320

8. PERFORMING ORGANIZATION REPORT NUMBER
AFRL-SN-WP-TP-2006-122

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-2006-122

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

13. SUPPLEMENTARY NOTES
Conference paper submitted to the Proceedings of the 22nd Annual Review of Progress in Applied Computational Electromagnetics (ACES 2006).

PAO Case Number: AFRL/WS 06-0077, 09 Nov 2006. This report contains color.

If this work is published, Applied Computational Electromagnetics Society may assert copyright. The U.S. Government is joint author of the work and has the right to use, modify, reproduce, release, perform, display, or disclose the work.

14. ABSTRACT

Leaky-wave antennas offer the potential for a wide operational bandwidth from a very thin antenna. Recently, a leaky-wave antenna that is half the usual width of a planar microstrip leaky-wave antenna was proposed. One of the major advantages of this design is that it requires only a single, rather simple, feed mechanism. To maintain the full potential bandwidth of that antenna, an appropriate termination is required. In this paper, a termination scheme is proposed and validated using a finite element-boundary integral model. In addition, a dual half-width antenna is shown to allow greater flexibility as compared to traditional microstrip leaky-wave antennas.

15. SUBJECT TERMS
microstrip, leaky-wave, transverse resonance, traveling wave antenna, wide bandwidth

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

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

Termination of a Half-width Leaky-wave Antenna

Daniel Killips, Michael Corwin, Leo Kempel and Stephen Schneider

***Abstract*—Leaky-wave antennas offer the potential for a wide operational bandwidth from a very thin antenna. Recently, a leaky-wave antenna that is half the usual width of a planar microstrip leaky-wave antenna was proposed. One of the major advantages of this design is that it requires only a single, rather simple, feed mechanism. To maintain the full potential bandwidth of that antenna, an appropriate termination is required. In this paper, a termination scheme is proposed and validated using a finite element-boundary integral model. In addition, a dual half-width antenna is shown to allow greater flexibility as compared to traditional microstrip leaky-wave antennas.**

***Index Terms*—microstrip, leaky-wave, transverse resonance, traveling wave antenna, wide bandwidth.**

I. INTRODUCTION

MICROSTRIP leaky-wave antennas offer the potential for a low-profile antenna with greater bandwidth than microstrip patch antennas. This is principally due to the fact that the radiation mechanism is attributed to a traveling-wave as compared to the standing-wave that is responsible for radiation by a microstrip patch antenna. Traditional microstrip leaky-wave antennas are wide microstrip structures fed in such a way that the dominant mode is the leaky-wave rather than transmission-line mode. This mode suppression is rather challenging in traditional leaky-wave antennas since feed structures must be designed to preferentially excite the leaky-wave mode. Oliner [1] made significant contributions to the theory of leaky-wave structures as antennas. Menzel [2] utilized periodic slots to suppress the dominant mode while Lin [3] investigated various feed structures for preferentially exciting the chosen mode. The bandwidth of these antennas is another important issue since one of the prime rationale for a leaky-wave antenna is to have a low-profile, wide bandwidth antenna. Various methods have been investigated to increase bandwidth including tapering the microstrip structure [4]-[5].

An alternative structure, the microstrip half-width leaky-wave (HWLW) antenna was recently proposed by Thiele *et al*. [6]. This structure places a metallic wall along one long edge of the antenna thereby causing unbalanced radiation to occur from the magnetic current along the opposite long edge. The radiating mode travels from the source to the termination. However, if there is no termination, the reflected wave sets up a standing-wave that limits the VSWR bandwidth of the antenna. Alternatively, the antenna could be made very long so that the attenuation associated with the leaky-wave can diminish end reflections; however, this it not a practical solution for many applications. Significant bandwidth can be obtained using this structure with the advantage of requiring only a single probe feed. In a recent paper, two termination schemes were investigated showing that a lumped load has potential for effectively dampening a backward traveling wave [7].

In this present paper, the lumped load termination scheme is improved demonstrating that a significant portion of the available bandwidth can be used for radiation. The performance of this antenna will be investigated using a hybrid finite element-boundary integral (FE-BI) model and compared to measured data.

II. MICROSTRIP LEAKY-WAVE ANTENNAS

A. Leaky-wave Antenna Theory

The fundamental mode of a microstrip line, the so-called EH_0 mode, is not a radiating mode (hence the popularity of microstrip transmission lines). The electric and magnetic fields for this mode are shown in Figure 1. Radiation from such a structure can be represented by two long magnetic current walls separated the width of the microstrip. Since these current sources are out-of-phase, the co-polarized radiated field in a plane bisecting the width of the antenna is identically zero. Therefore, as an end-fire antenna, such a microstrip is unsuitable.

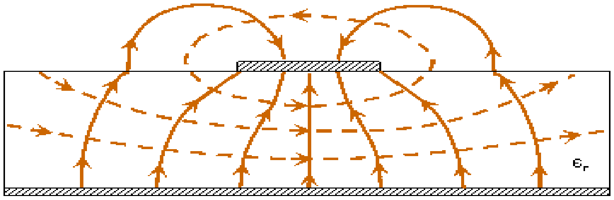

Figure 1. Field diagram for the EH_0 mode (E-field = solid, H-field = dashed).

Rather, higher-order modes must be preferentially excited to realize a radiating traveling wave structure. The first higher-order mode, the EH_1 mode, is one such radiating mode. This mode (shown in Figure 2) exhibits electric field odd symmetry

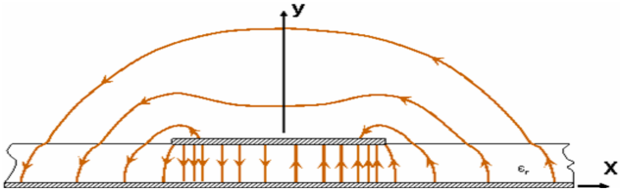

Figure 2. Field diagram for the EH$_1$ mode (E-field = solid, H-field = dashed).

about the axial centerline of the antenna as compared to the even symmetry of the EH_0 mode. The radiating magnetic currents are now in-phase and hence radiate along the axis of the antenna.

The current on either wall can be represented as

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

where the attenuation term $\alpha(z,f)$ and the propagation term $\beta(z,f)$ is 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 microstrip. The attenuation and propagation terms for an axially invariant structure can be determined using the Transverse Resonance Method (TRM) [9]. Once the propagation parameters are know, the driving point impedance for a semi-infinite line can be determined using an open waveguide model, viz. [4]-[5][1] as

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

In (2), the effective microstrip with is given by Wheeler's approximation [10]

$$w_{eff} = h\left\{\frac{w}{h} + \frac{2}{\pi}\ln\left[2\pi e\left(\frac{w}{2h} + 0.92\right)\right]\right\} \quad (3)$$

Use of (2) and (3), with the propagation parameters provided by TRM, allows determination of the appropriate feed and load locations along the width of the strip.

B. 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 15 mm while the half-width strip width is 7.5 mm. The strip is taken to be 190 mm long for the simulations and measurements and it is infinite for the TRM analysis. The propagation terms as determined using the transverse resonance method is shown in Figure 3. Traditionally, the leaky-wave region of operation is defined between the frequency such that $\alpha = \beta$ to the frequency such that $\beta = k_0$; hence, for the example presented, approximately from 6 GHz to 8 GHz. Using this information, along with (2) and (3), the driving point impedance for a semi-infinite version of this realization of the antenna is shown in Figure 4 where the feed point is taken at the transverse midpoint of the HWLW antenna. This feed location was chosen for convenient fabrication and to realize a reasonable match to a 50Ω load.

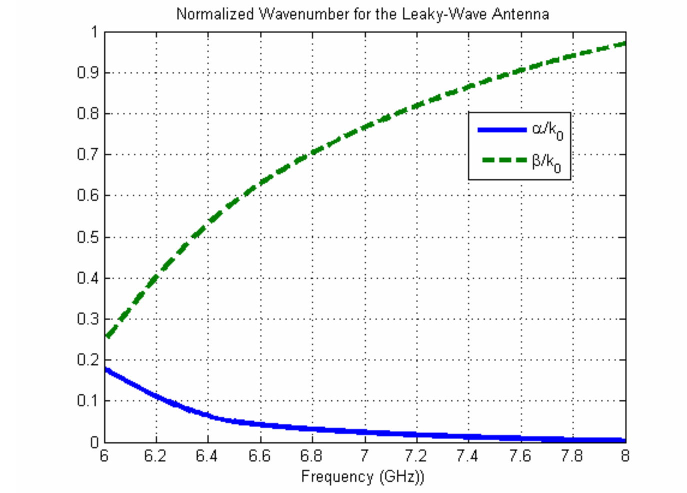

Figure 3. Normalized attenuation and phase constant for a leaky-wave antenna.

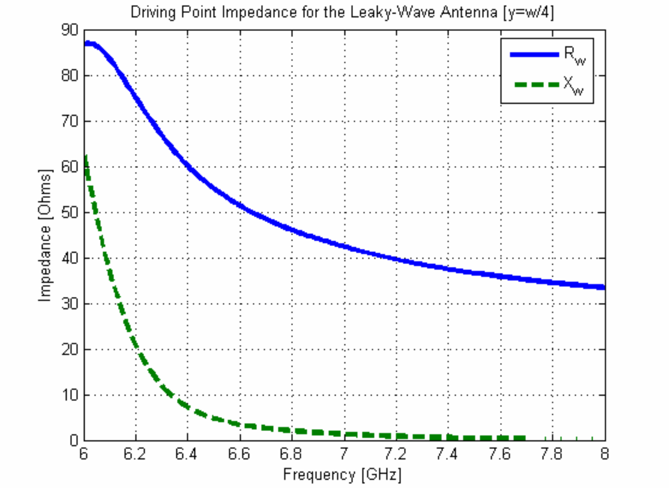

Figure 4. Driving point impedance at the center of the half-width strip width for this leaky-wave antenna.

As can be seen, the impedance seen at the input port of the antenna is dispersive and hence a perfect match to a $50\,\Omega$ line is not possible across the entire operational bandwidth.

III. FINITE ELEMENT-BOUNDARY INTEGRAL MODEL

The data presented in Figure 4 indicates that a $50\,\Omega$ lumped load placed approximately at the transverse mid-point of a half-width antenna should make a fairly good termination for the majority of the operational bandwidth (Note: The computed impedances, as will be seen, typically have come in a bit lower than the TRM predictions). To assess this hypothesis, transverse resonance modeling is insufficient. Rather, a full-wave, three-dimensional model is required. For this work, a hybrid finite element-boundary integral model

---

[1] There is a typographical error in the expression in [4] where the sine function should be squared as shown in (2). The expression is correct in [5].

was used employing brick elements [11]. The shorted side of the HWLW antenna is modeled using an infinitesimally thin perfectly conducting wall running from one end of the strip to the other end. The lumped loads were modeled as infinitesimally thin loads placed 3.75 mm from the shorted edge of the half-width antenna. The feeds are modeled likewise as infinitesimally thin probe feeds placed 3.75 mm from the shorted edge of the antenna. Both the feed and the load are at the two edges of the strip.

The approximate model described in (2-3) is combined with the impedance transformation equation for a lossy transmission line to find the input impedance given a 50Ω load. In this approximate model, the effective width (3) and the effective length [12]

$$\Delta L = 0.412h\left(\frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258}\right)\left(\frac{w/h + 0.264}{w/h + 0.8}\right) \qquad (4)$$

are used to model the effects of fringing fields. Figure 5 compares this approximate model to the VSWR results computed using the hybrid FE-BI approach.

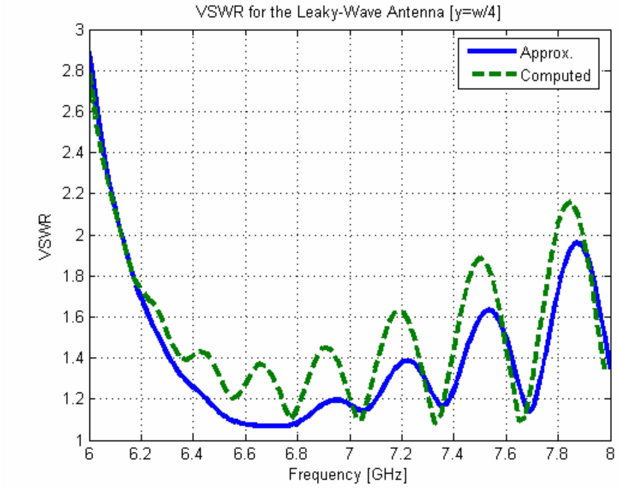

Figure 5. Comparison of approximate and computed VSWR data for the half-width leaky-wave antenna.

The agreement is reasonably good considering the approximations made (e.g. transverse-resonance method, open waveguide model, and effective widths and lengths).

IV. COMPARISON WITH MEASURED DATA

To assess both the approximate and computational models discussed above, an experiment was conducted in a compact anechoic chamber. The shorting wall in the half-width antenna was approximated using shorting pins that were 5 mm apart running the length of the antenna strip. The ports were attached to an HP-8510 vector network analyzer. A representative radiation pattern, comparing computed and measured data, is shown in Figure 6.

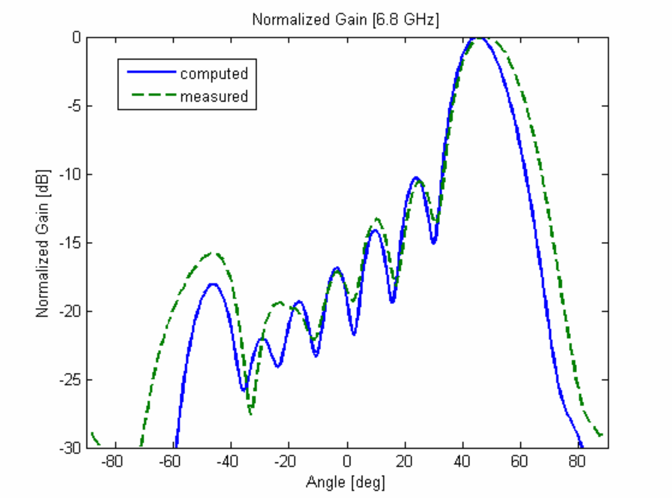

Figure 6. Comparison of computed and measured radiation pattern from a half-width, leaky-wave antenna at 6.8 GHz.

The agreement is reasonably good considering that the shorting wall was not solid, the FE-BI model used a probe feed, and the actual ground plane was finite while the modeled one was infinite.

V. CONCLUSION

The design, simulation, and measurement of the termination for a half-width antenna were presented. The location of the lumped load was chosen based on results obtained from an approximate model for the characteristic impedance that utilized the transverse resonance method to determine the complex wave number, an open waveguide model to determine the characteristic impedance of the structure, and the usual effective length and width terms to represent the effects of fringing fields. The predicted VSWR of this model were compared with a full-wave, hybrid finite element-boundary integral model. The radiation pattern was measured at a frequency within the leaky-wave operating regime and compared with computed results obtained from the full-wave solution. The agreement in the pattern was quite good and the agreement between the computed VSWR and approximate VSWR is within expectations considering the approximations used.

The effectiveness of this termination scheme is evident by the forward-to-backward lobe ratio. The backward lobe, attributed to any leaky-wave reflected from the termination, is 15 dB below the forward lobe. Half-width leaky-wave antennas have the advantage of simplified feeding methods and reduced surface area requirements. Note that since the characteristic impedance (as shown in Figure 4) is dispersive, back-suppression performance using a lumped load will vary. An adaptive load, where the impedance of the load mimics the conjugate of the driving point impedance, would be propitious.

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] 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.

[4] 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.

[5] 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.

[6] 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.

[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] 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.

[9] K.S. Lee, "Microstrip Line Leaky Wave Antenna", Ph.D. Dissertation, Polytechnic University, June 1986.

[10] H.A. Wheeler, "Transmission line properties of parallel strips separated by a dielectric sheet," *IEEE Trans. Microwave Theory Tech*., 13, pp. 172-185, 1965.

[11] J.L. Volakis, A. Chatterjee, and L.C. Kempel, *Finite Element Methods for Electromagnetics*, IEEE Press: Piscataway, N.J., 1998.

[12] C.A. Balanis, *Antenna Theory: Analysis and Design*, 3rd Ed., Chapter 14, Wiley: New York, 2005.