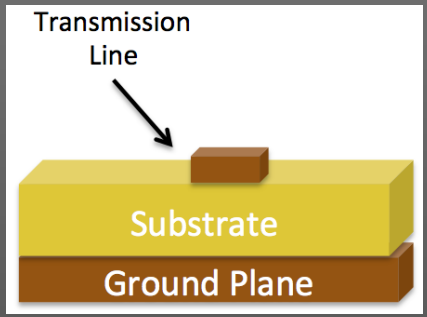
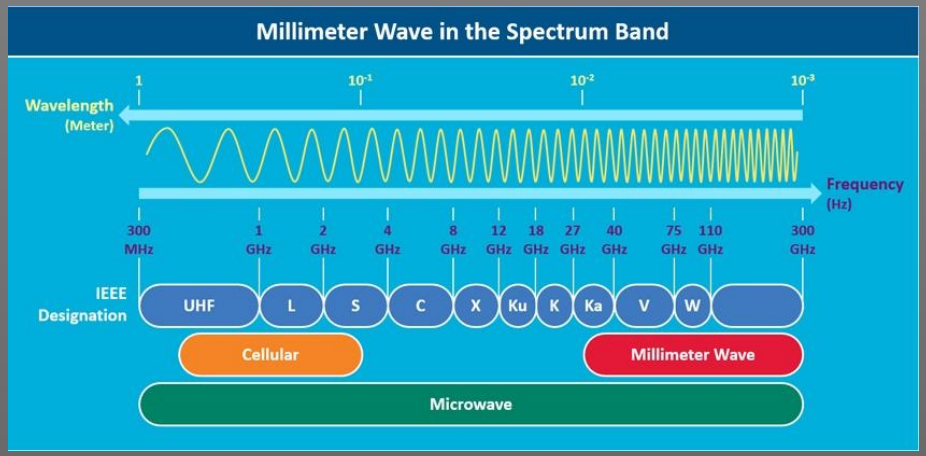
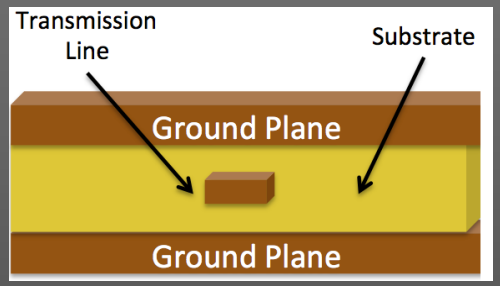






GWT/Twin Cities IEEE MTT-S Seminar
December 12th, 2017

Dominant-mode Leakage on Stripline and Microstrip Transmission-line Structures at Millimeter Wave Frequencies: Issues & Solutions

David Nghiem, Ph.D.

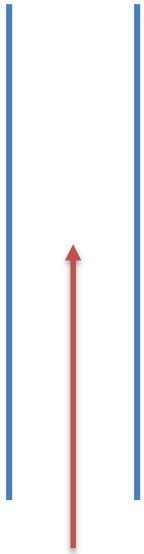
GWT CORPORATION

What is a dominant leaky mode?

Leaky modes have been found on a variety of wave-guiding structures. For transmission-line applications, their presence is undesirable since they carry energy away from the structure, thus causing additional loss on the line and interference between circuit elements. Of particular interest for planar transmission-line structures are dominant leaky modes. The term “dominant” implies that the strip current is similar to that of the conventional transverse-electromagnetic (TEM) mode.

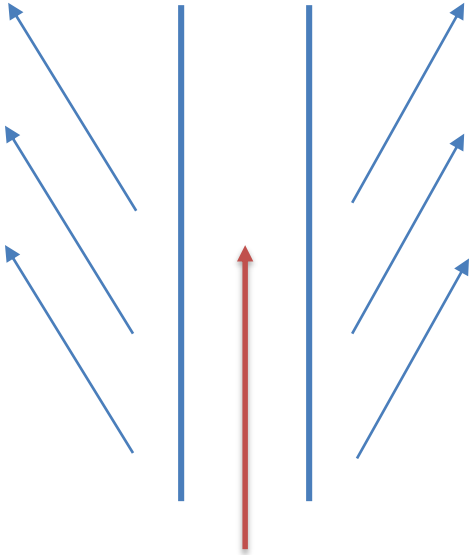
TEM Mode vs. Dominant Leaky Mode

Conventional TEM Mode



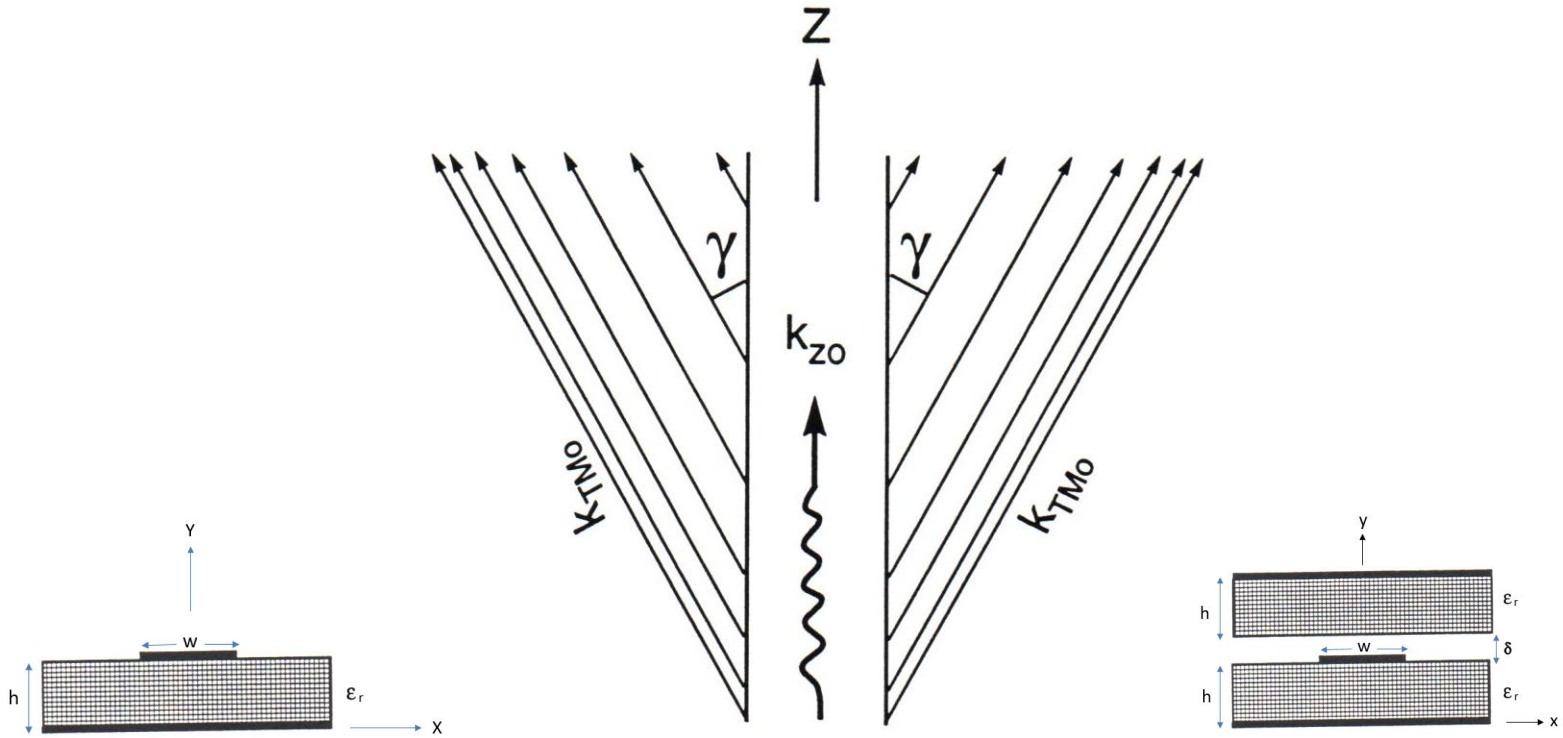
Proper Mode
Bound Mode

Dominant Leaky Mode



Improper Mode
Unbounded Mode

Dominant Leaky Mode – Leakage Angle

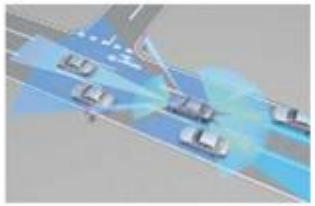


$$k_{zo} = \beta - j\alpha$$

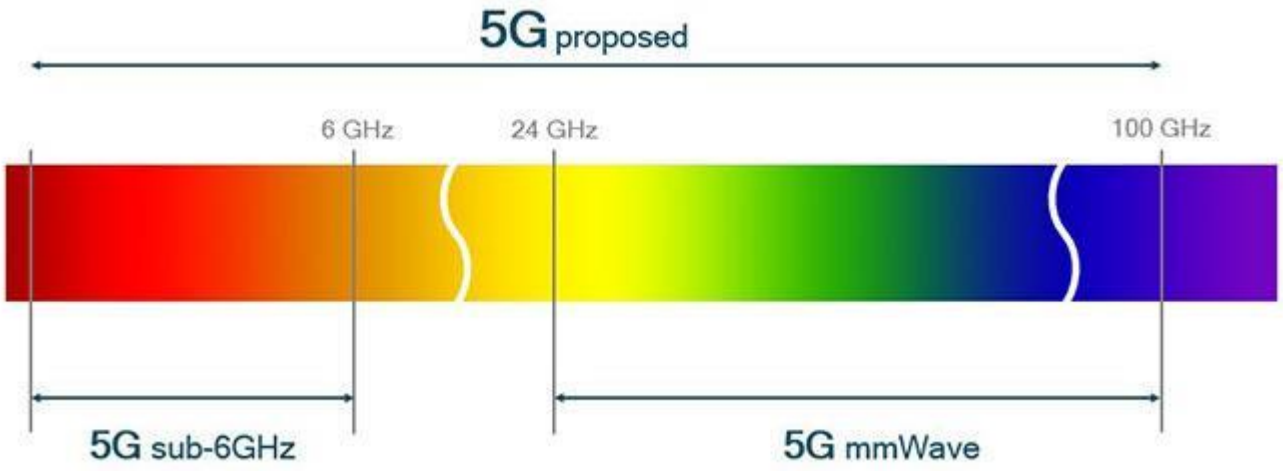
Top view of the strip for the stripline or microstrip structure. A leaky mode leaks energy away from the strip at an angle $\gamma = \cos^{-1} \beta / k_{TMo}$, where β and k_{TMo} are, respectively, the phase constant of the leaky mode and the transverse wavenumber of the TM_0 mode of the background structure.

Millimeter Wave Applications

1) 5G
2) Automotive Radar
3) Contactless Connector
4) Imaging
5) Skin Cancer Sensor

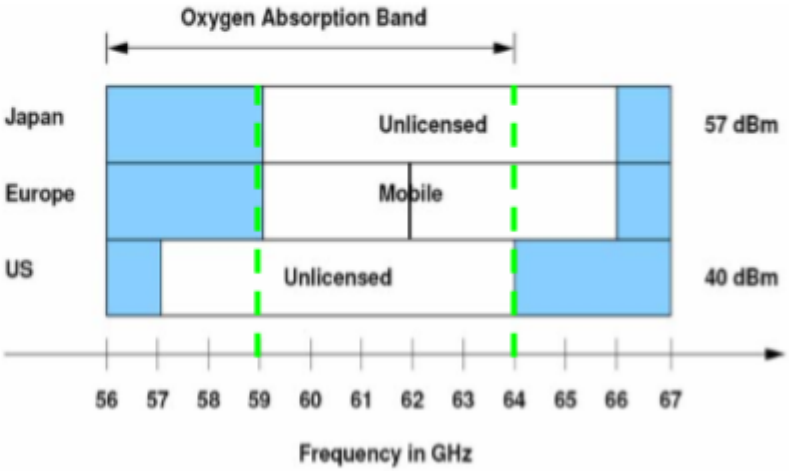


Proposed 5G Frequency Spectrum

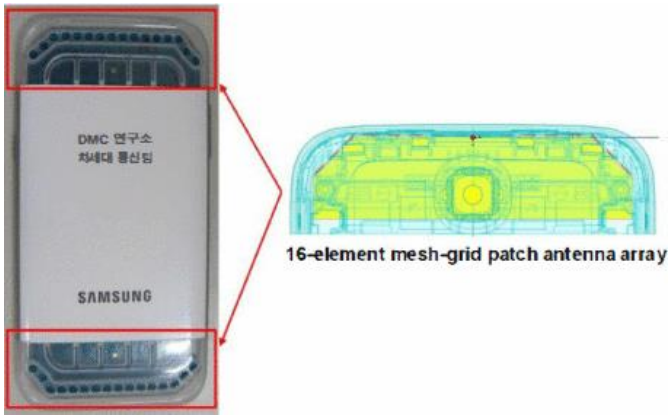


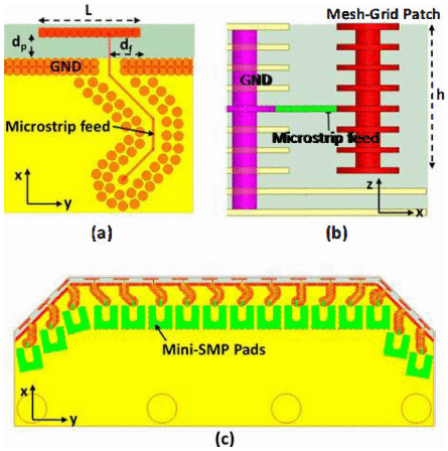
Proposed 5G Frequency Spectrum

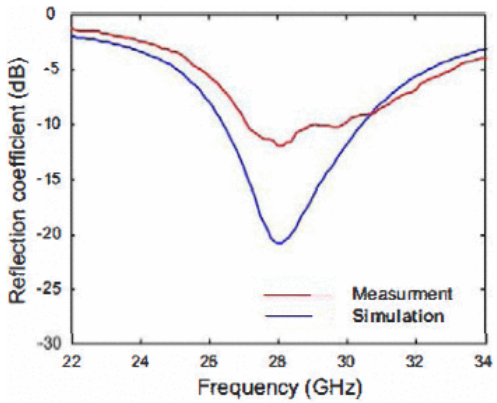
- Worldwide 5 GHz unlicensed bandwidth
- Data rate > 1 Gbps
- Applications
  - wireless USB2.0
  - wireless gigabit ethernet
  - wireless video (HDTV)
  - telecom backhaul

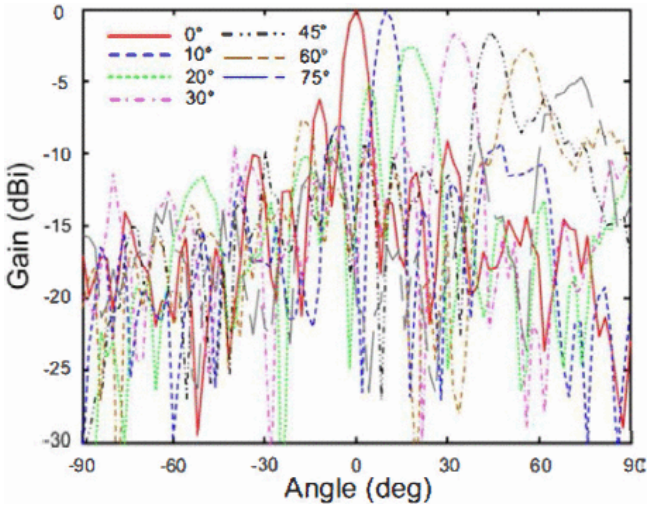


Samsung 28 GHz Antenna Array for Handset

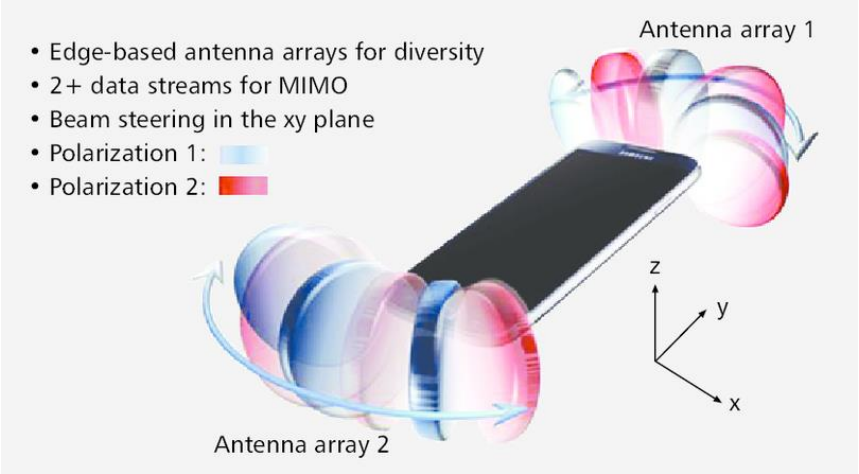






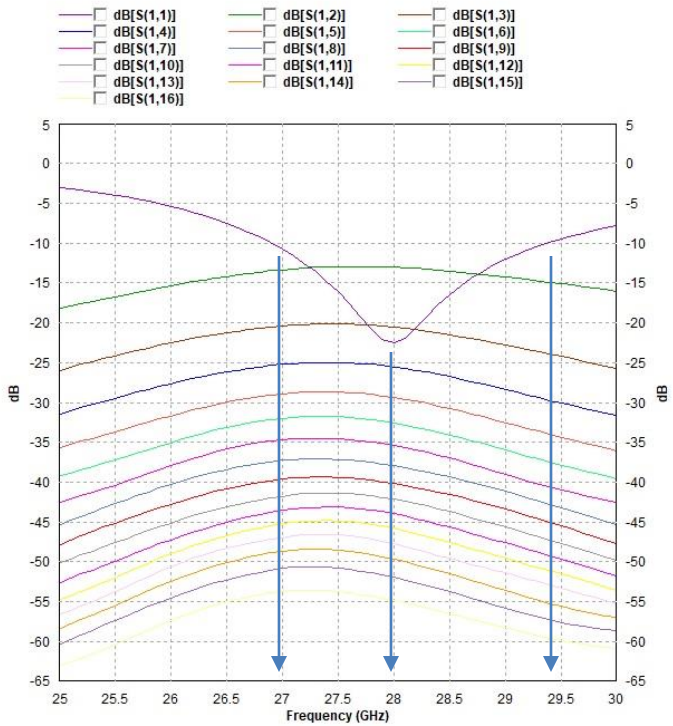


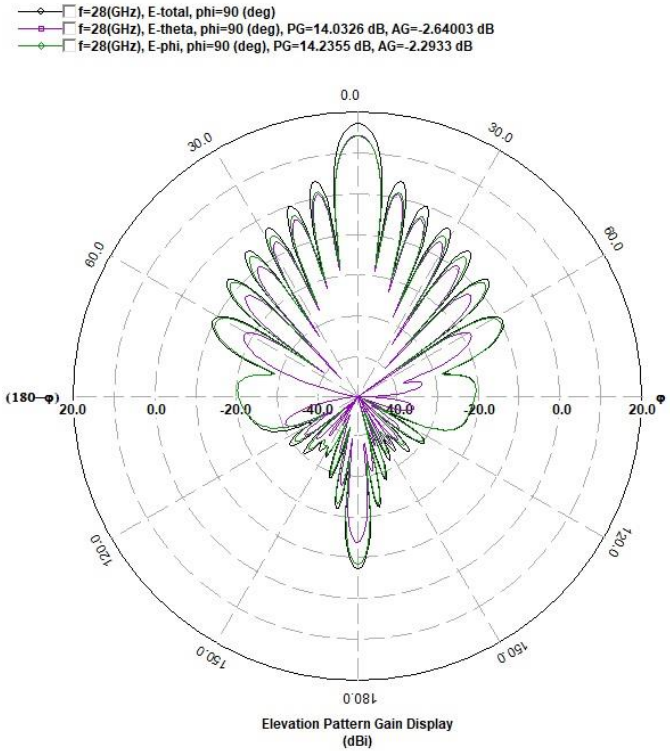
Linear Alternate-Polarization Antenna Array
5G Smartphone



GWT 16-Element Linear Dual-Polarization Antenna Array

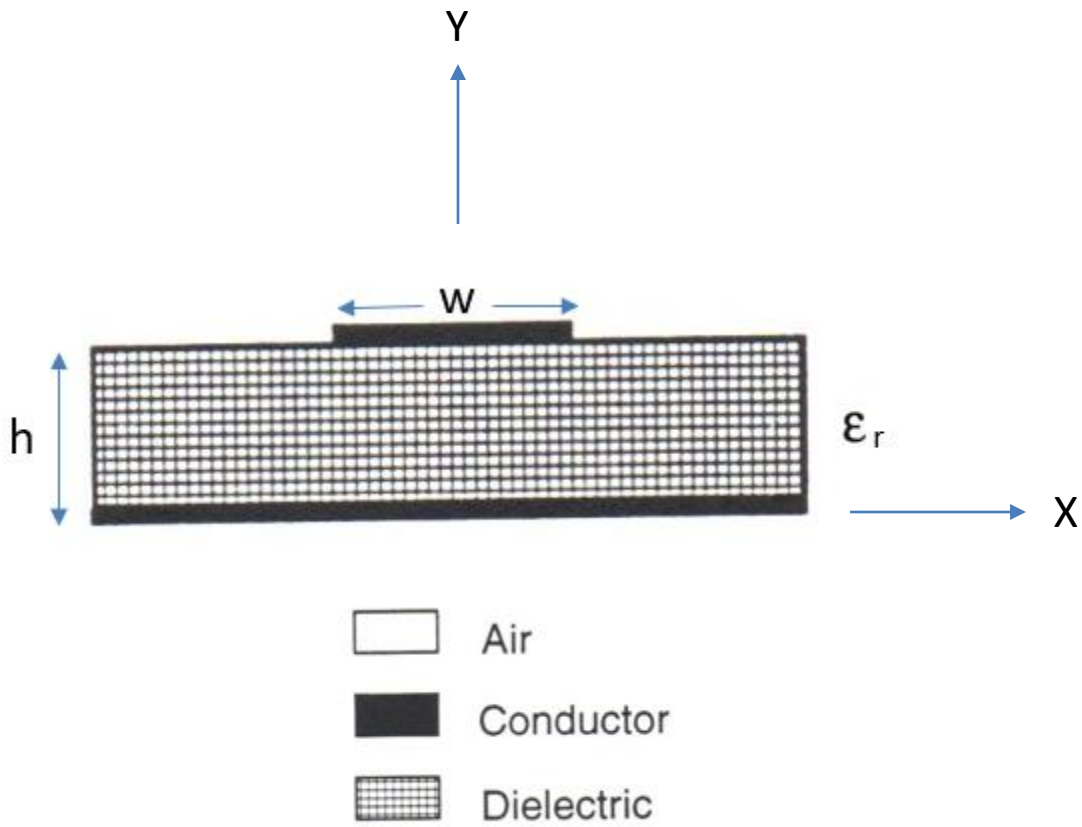
(No Circuit Loss – Uniform Excitation – λ/2 Element Spacing)





The dominant leaky-modes carry energy away from the structures, thus causing additional loss on the transmission-line and interference between circuits elements.

Dominant Mode Leakage on Microstrip

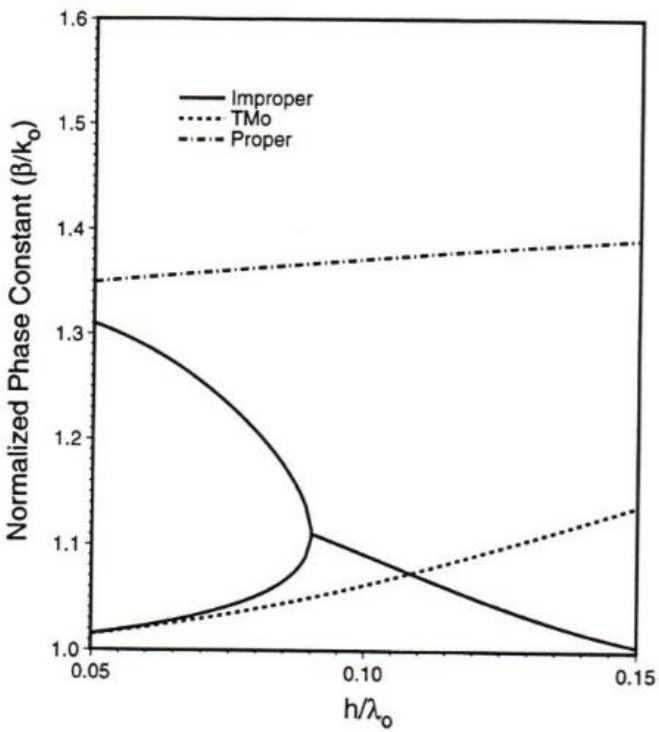


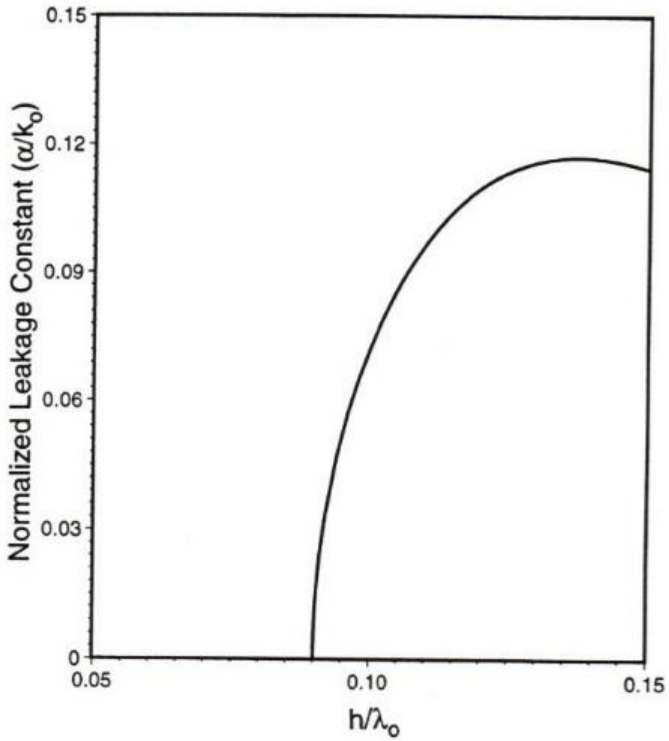
$$k_{zo} = \beta - j\alpha$$

Dominant Mode Leakage on Microstrip

Propagation Wavenumber

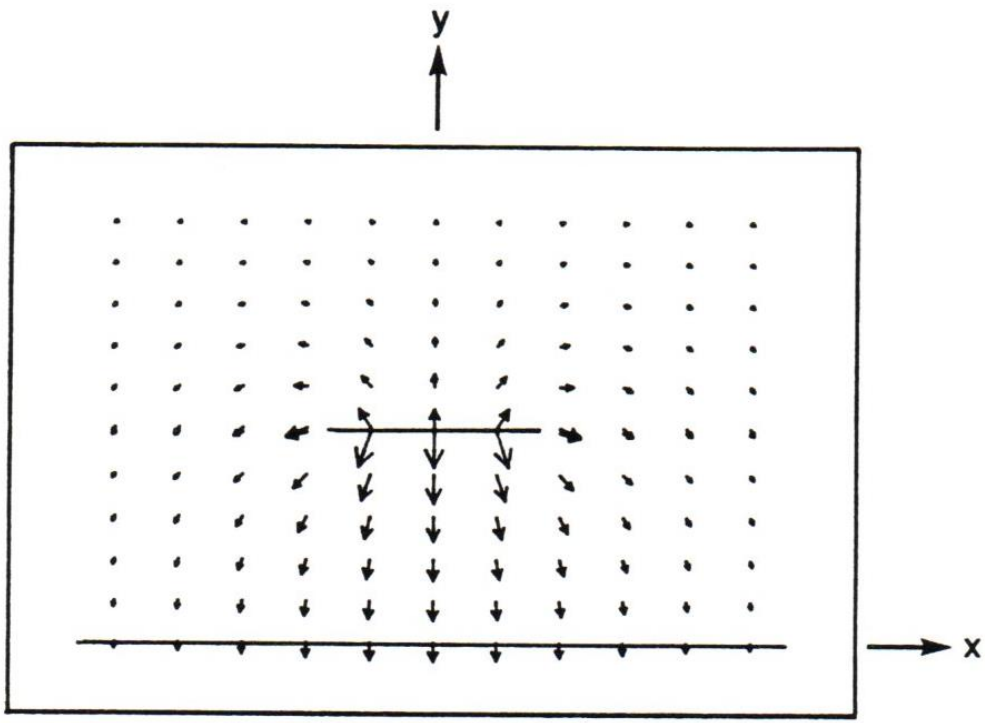
$$k_{zo} = \beta - j\alpha$$





Dominant Mode Leakage on Microstrip

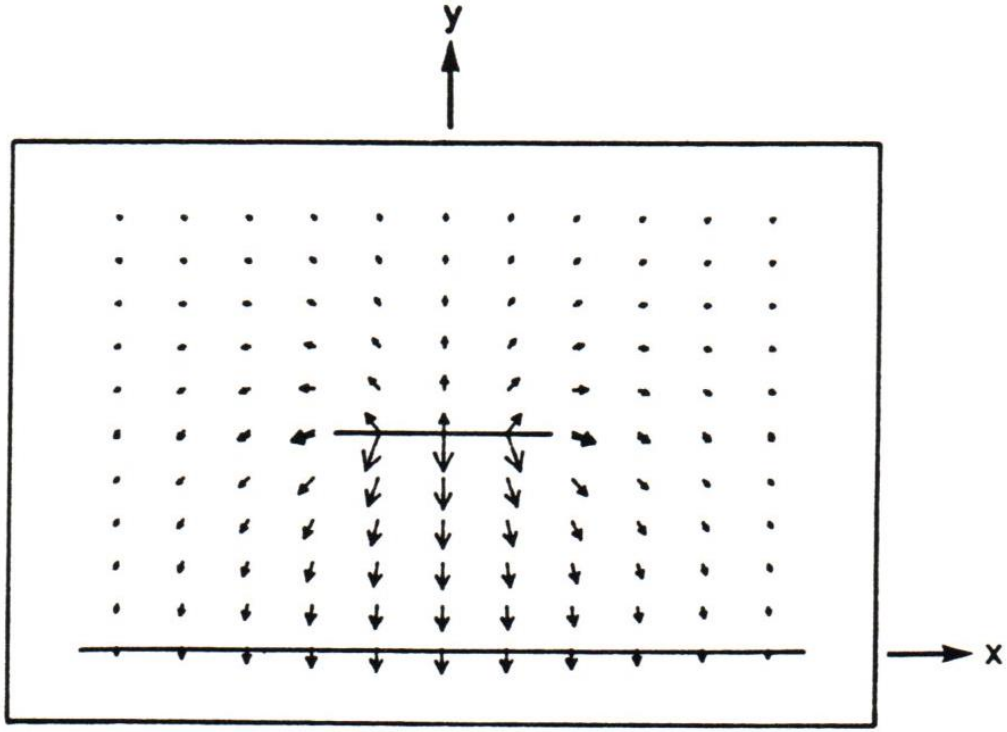
Real Part of E-field corresponding to the Proper Mode



$h/\lambda_0 = 0.125$

Dominant Mode Leakage on Microstrip

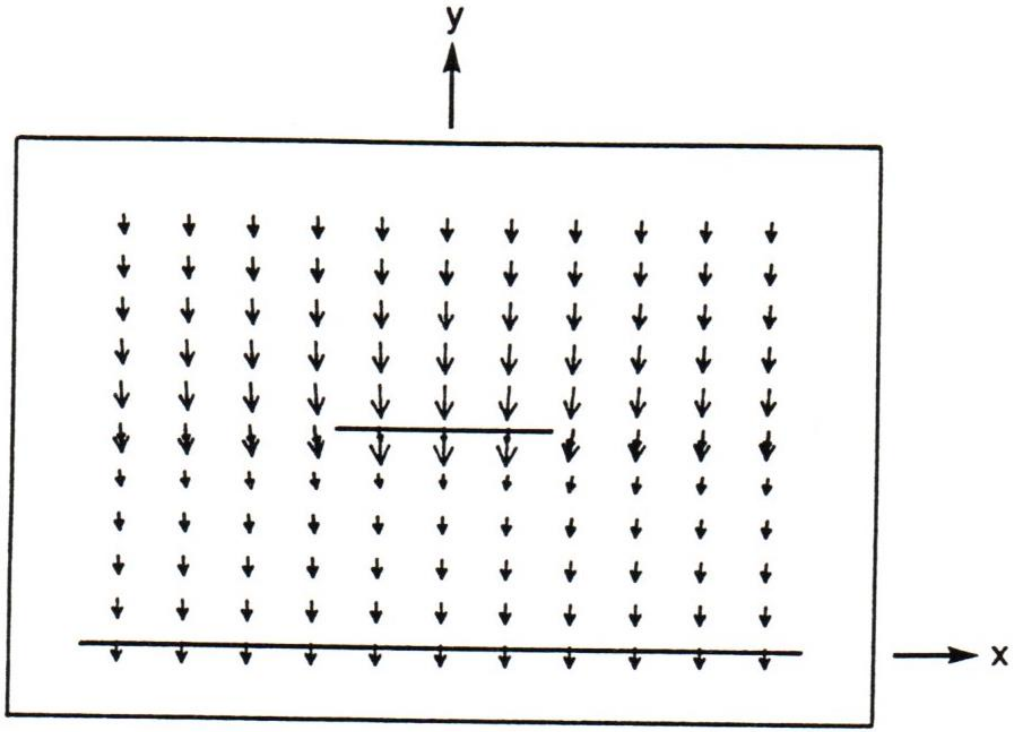
Real Part of E-field corresponding to the Improper Mode



$h/\lambda_0 = 0.125$

Dominant Mode Leakage on Microstrip

Imaginary Part of E-field corresponding to the Improper Mode

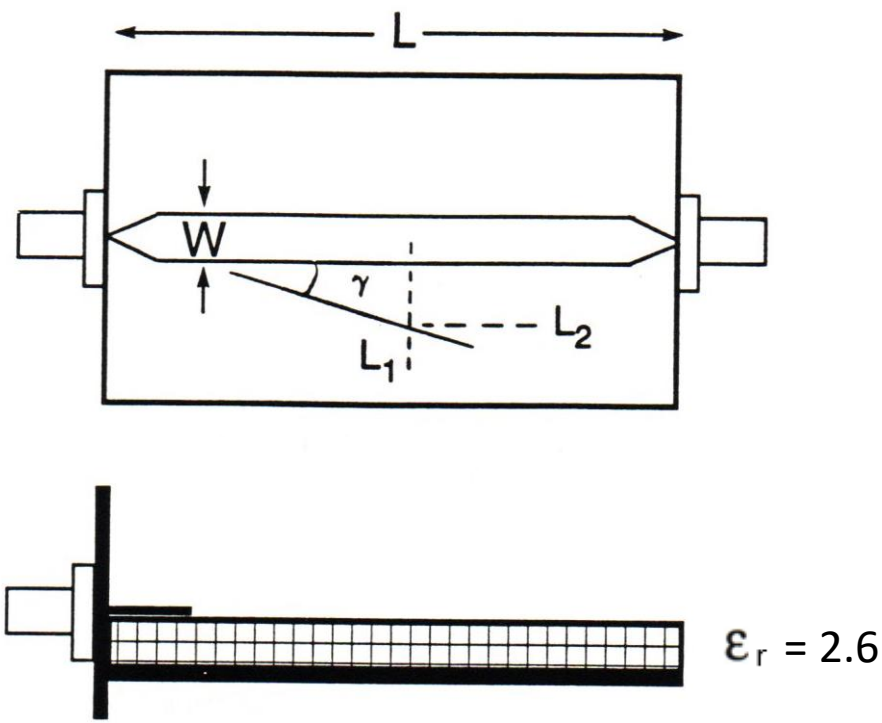


$h/\lambda_0 = 0.125$

Dominant Mode Leakage on Microstrip

Microstrip Structure used for the Experiment

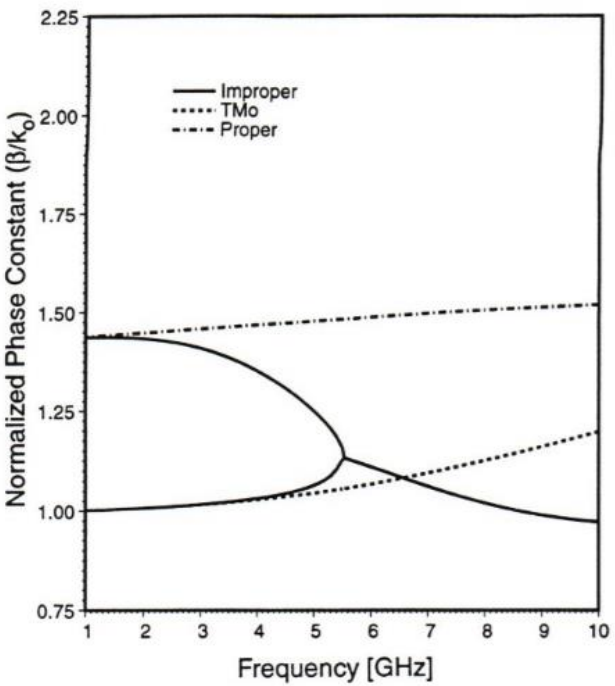
(h= 0.45 cm, W = 0.64 cm)

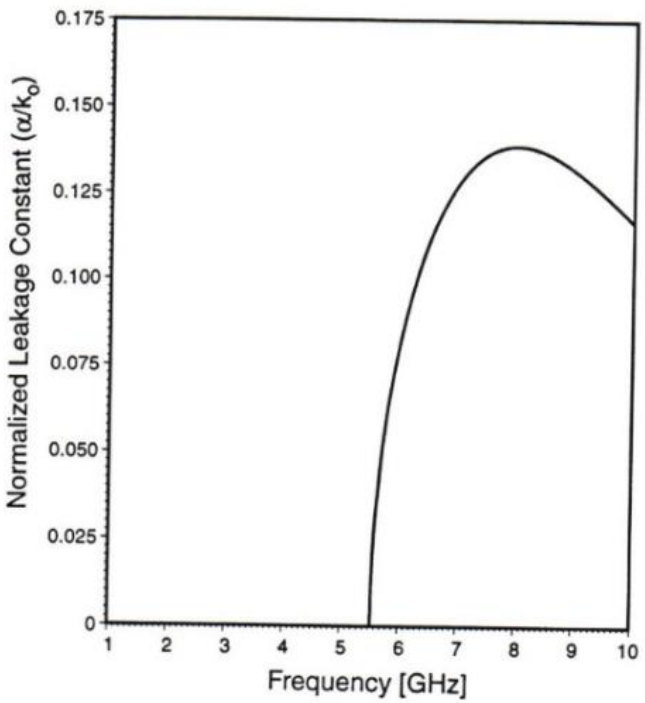


Dominant Mode Leakage on Microstrip

Propagation Wavenumber

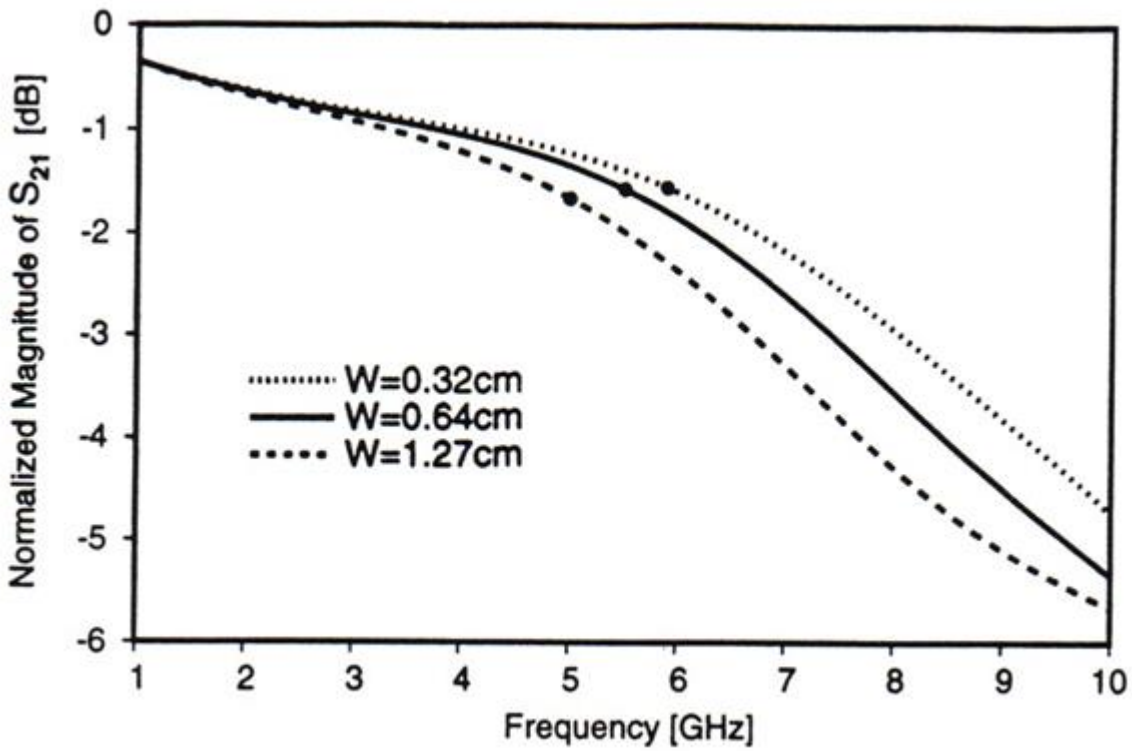
$$k_{zo} = \beta - j\alpha$$





Dominant Mode Leakage on Microstrip

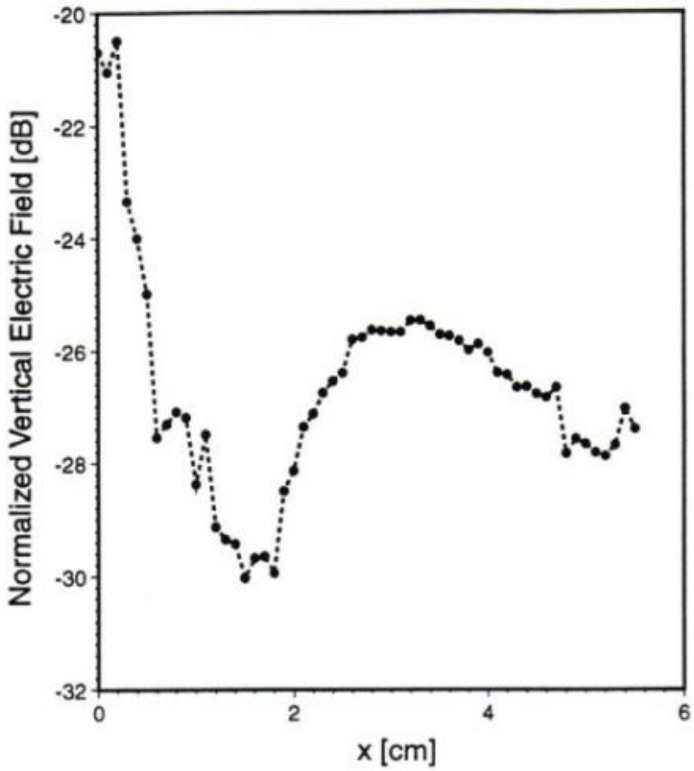
Measured Data



Dominant Mode Leakage on Microstrip

Measured Data

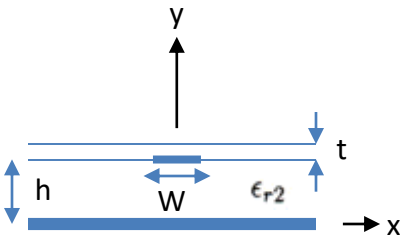
Measured vertical field $E_y(x, y = 0.0, z = 8.0 \text{ cm})$ versus x
$L = 15.25$ cm, at 8.0 GHz.



Dominant Mode Leakage on Microstrip

Propagation Wavenumber

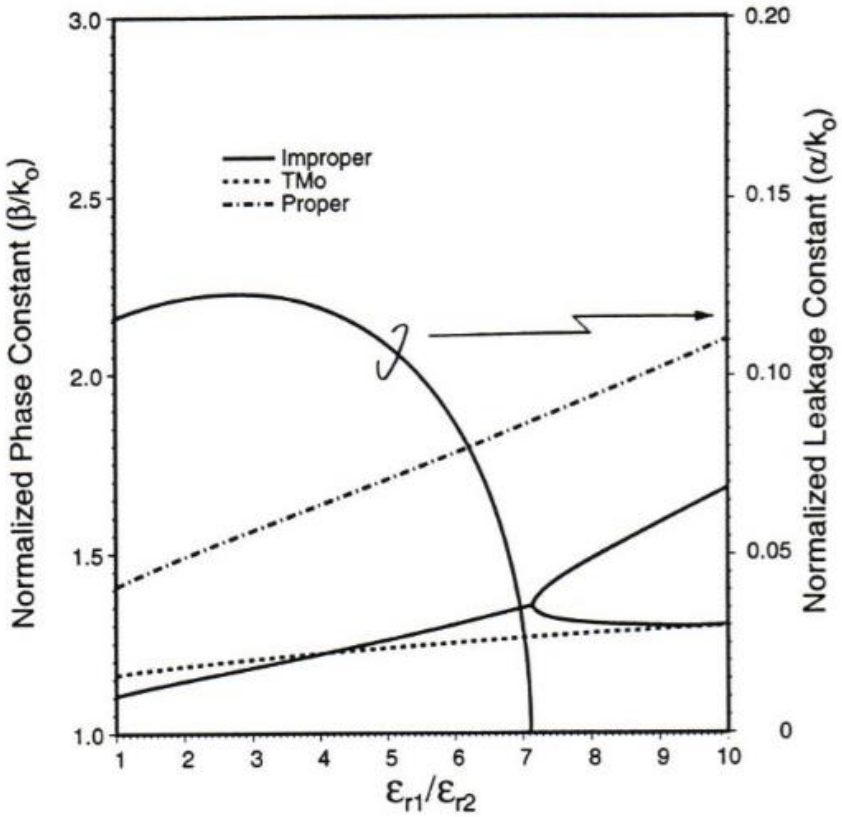
$$k_{zo} = \beta - j\alpha$$



$h = 0.15\lambda_0$

W = h/4

t = h/10



$\epsilon_{r2} = 2.2$

Dominant Mode Leakage on Microstrip

TEM Solution

Analysis/Synthesis Values

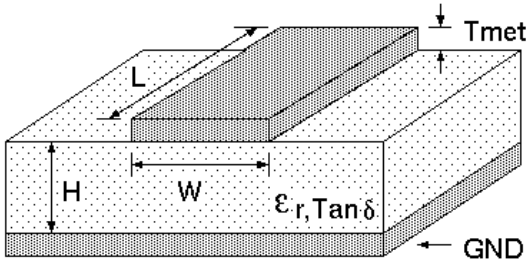
Width	5.81	--->	Z0 (Ohms)	50.002
Length	10	<---	Elec. Len. (degrees)	521.75
Frequency	30		GHz	

Output Values

Keff	2.0976	Loss (dB)	0.845
Physical Units	mm	Loss per length (dB/{Phys. Unit})	8.4E-2
Calculation Status	DONE	Skin depth {Phys. Units}	0
DeltaL {Phys. Units}	0.795	Delay (ns)	0.048
Len.-DeltaL {Phys. Units}	9.205		

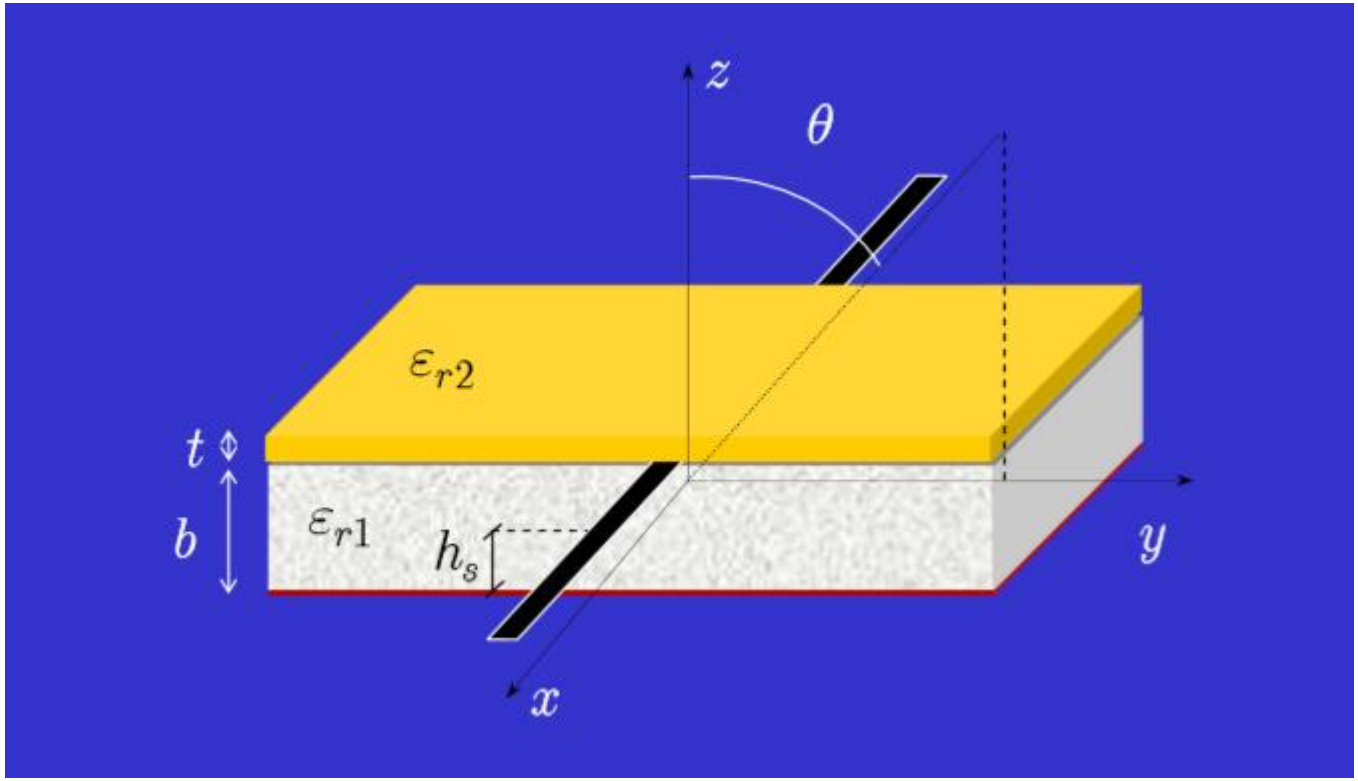
Substrate Parameters

Er	2.2	Rho	1
H	1.5	Rough	0.0
Tmet	.01	Tanδ	0.022



How about the leaky-mode solution?

Leaky Wave Antenna (LWA)



Leaky Wave Antenna (LWA)

- Leaky-wave antennas (LWAs) belong to the traveling-wave antenna family

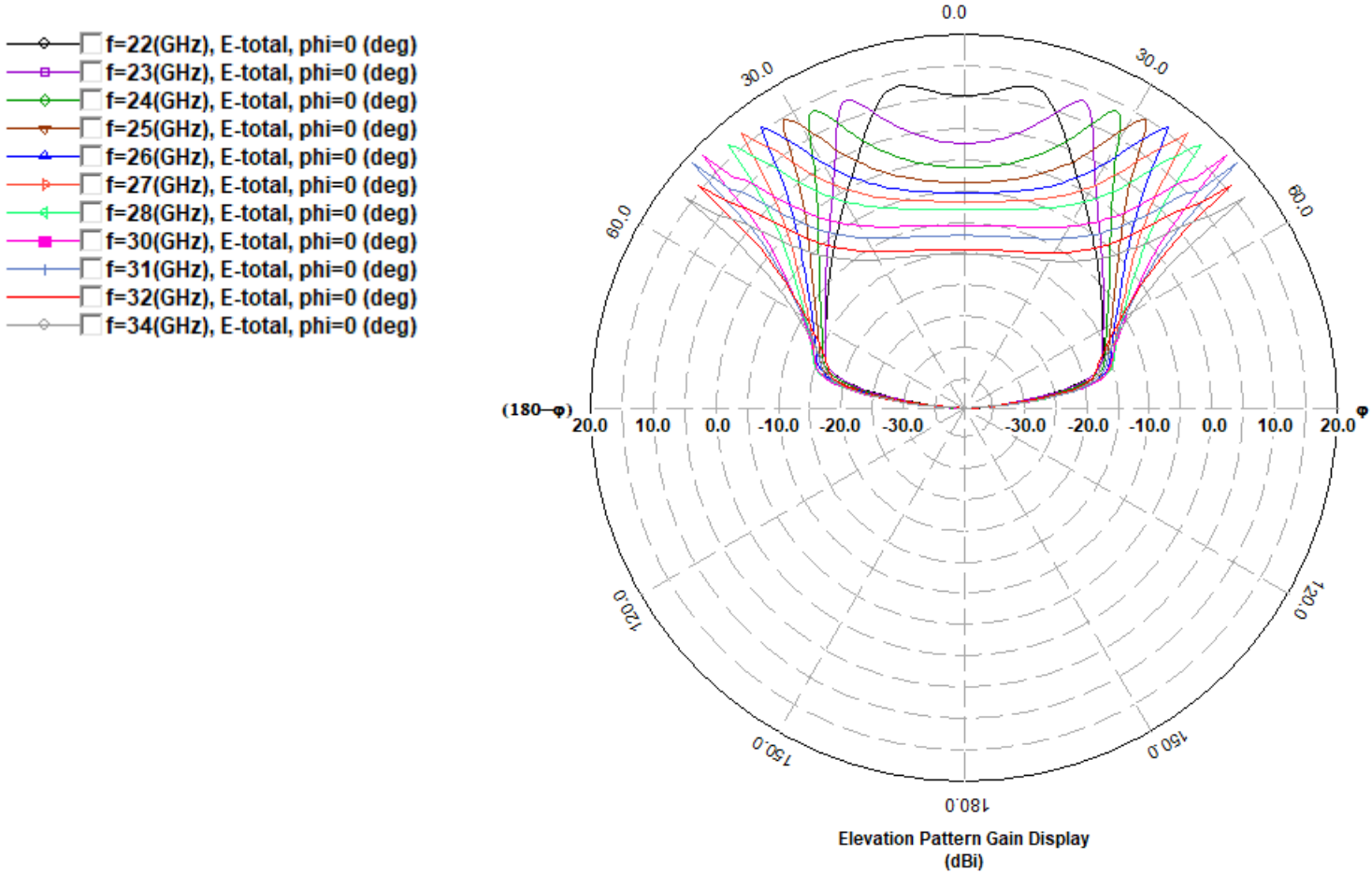
  ↓

  Radiation occurs from a traveling wave with a complex wavenumber $\beta - j\alpha$

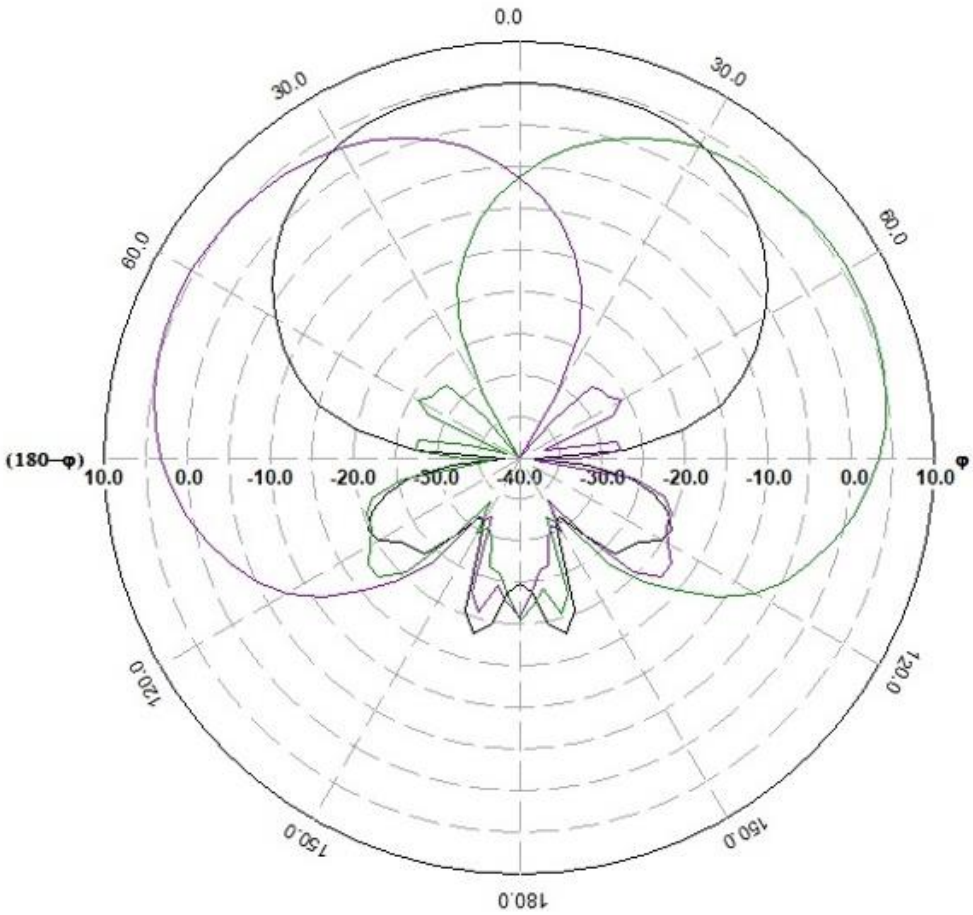
- Phase constant β controls the scan angle
  Attenuation constant α controls the beamwidth → Both are dependent on the geometry of the LWA structure

- LWAs made in printed-circuit fashion enjoy the advantages of:
  - being low profile
  - having structure simplicity
  - being compatible with easy integration

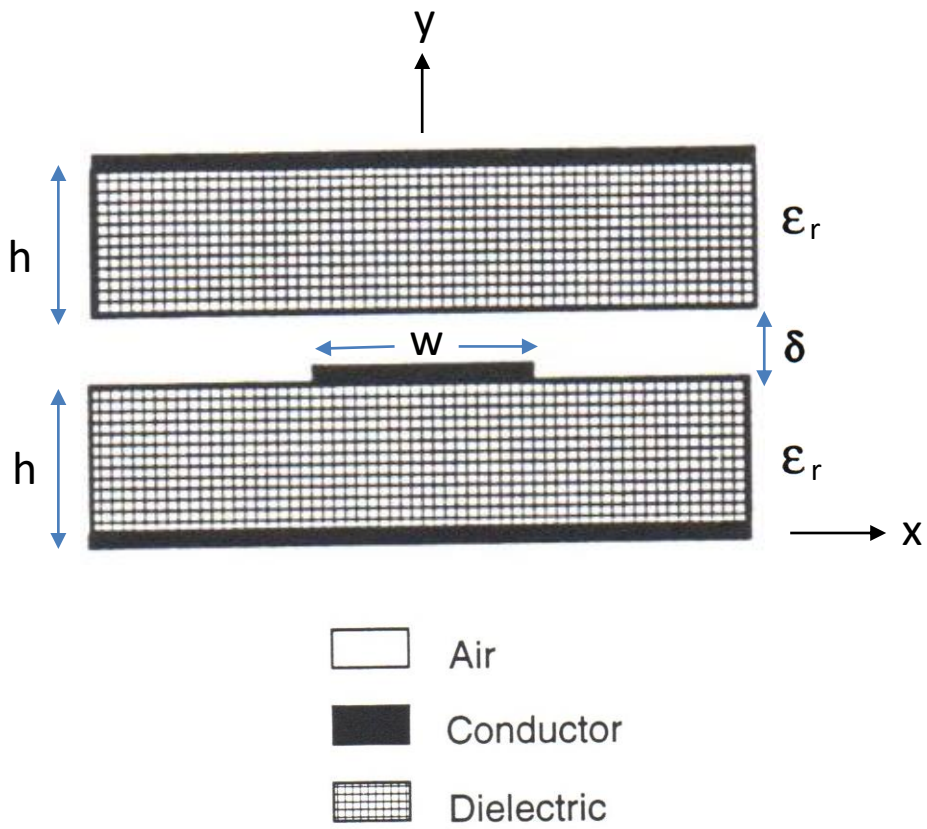
GWT Leaky Wave Antenna (LWA)



GWT Cost-effective Steerable Antenna



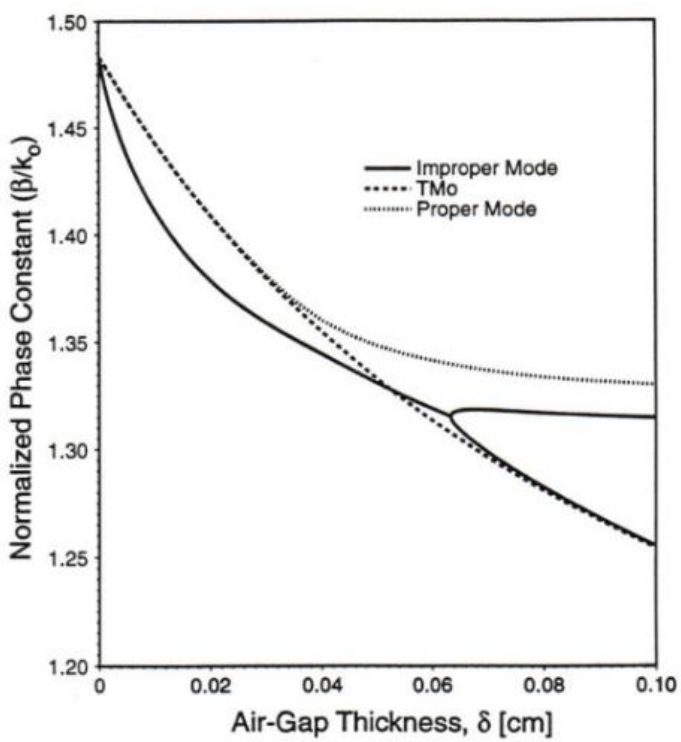
Dominant Mode Leakage on Stripline

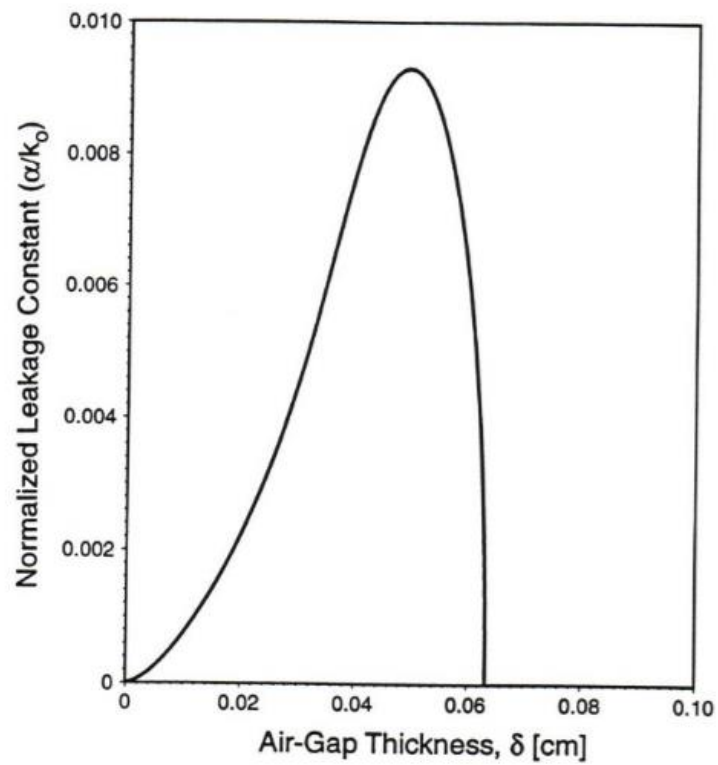


Dominant Mode Leakage on Stripline

Propagation Wavenumber

$$k_{zo} = \beta - j\alpha$$





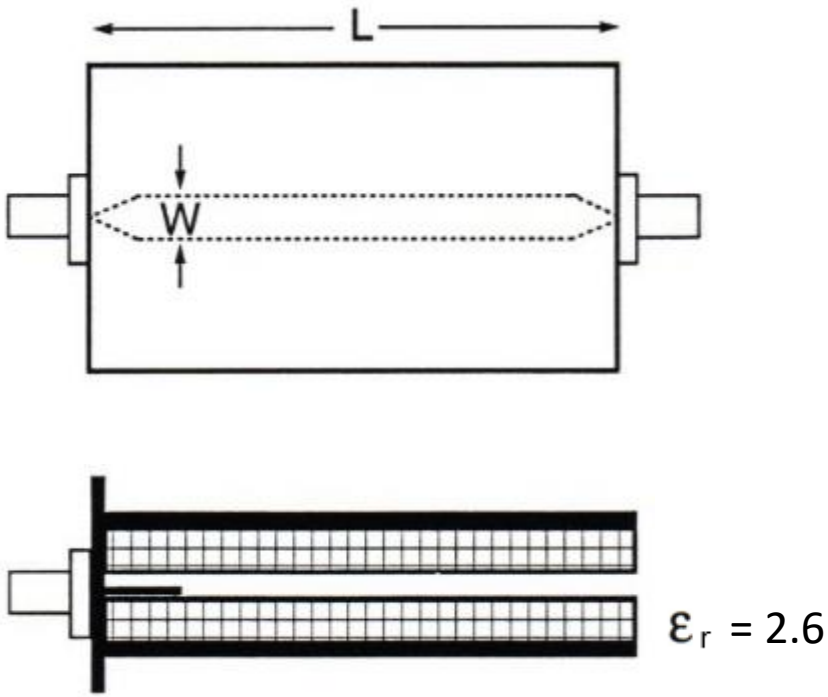
$h = W =$ 0.1 cm

$\epsilon_r = 2.2$, at 3.0 GHz

Dominant Mode Leakage on Stripline

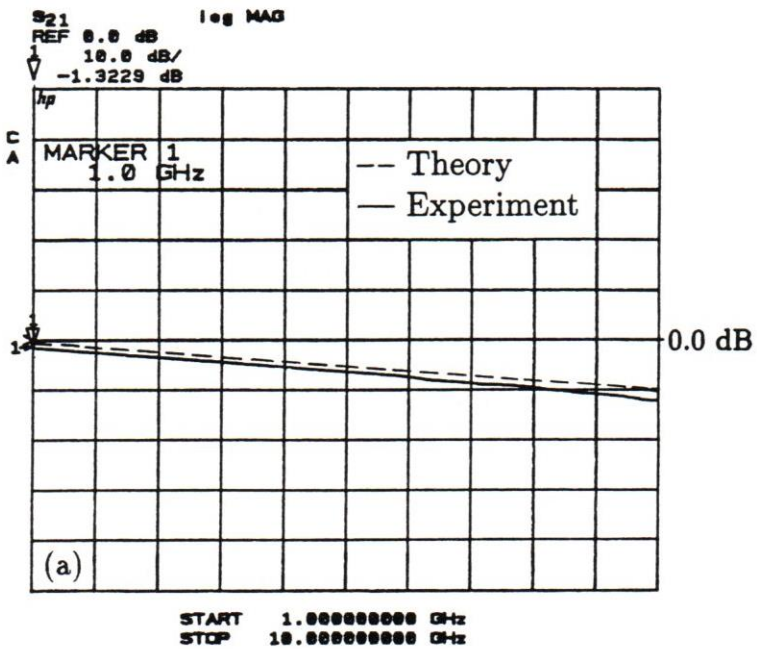
Stripline Structure used for the Experiment

(h= 0.45 cm, W = 0.65 cm)

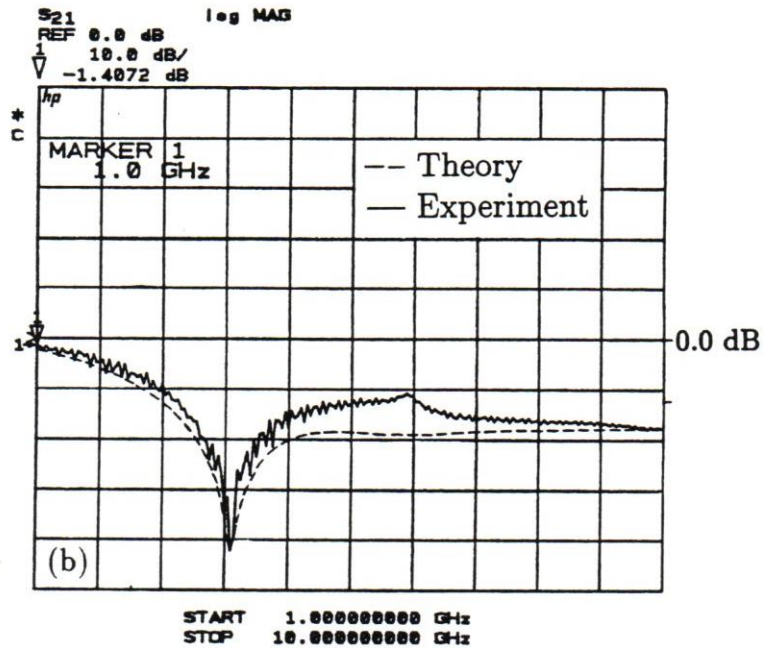


Dominant Mode Leakage on Stripline

Measured Data



$(\delta = 0)$

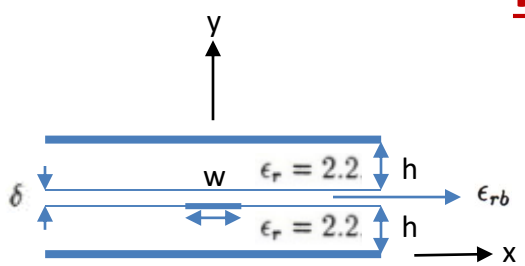


$\delta = 0.08$ cm

Dominant Mode Leakage on Stripline

Propagation Wavenumber

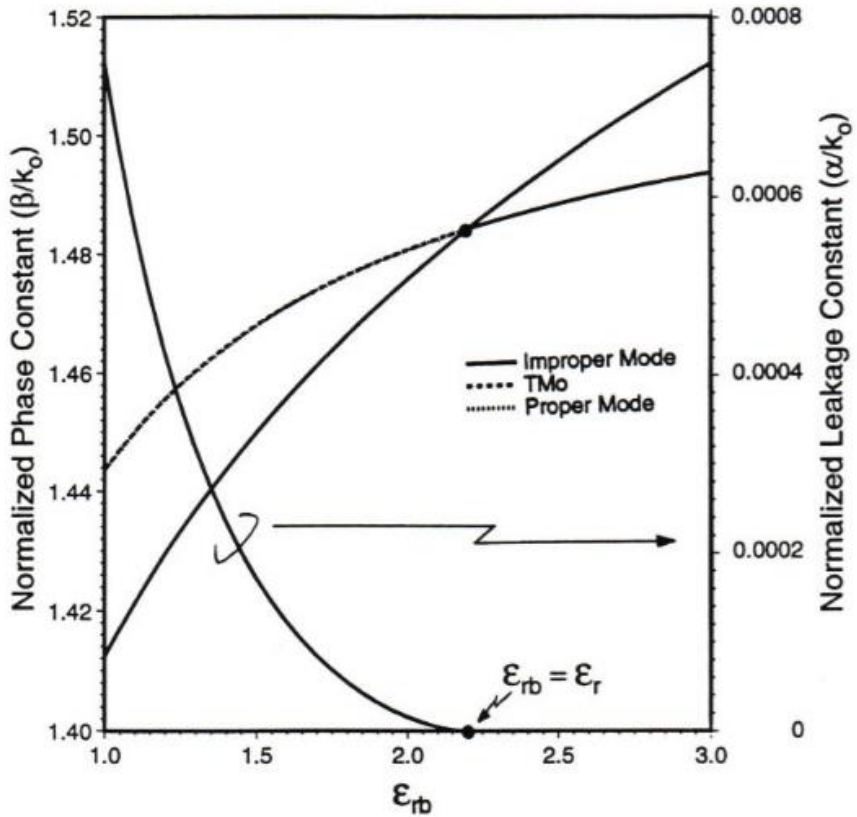
$$k_{zo} = \beta - j\alpha$$



$h = W = 0.1$ cm.

$\delta = 0.01$ cm,

Frequency = 3.0 GHz



References

"**A General Analysis of Propagation along Multiple-layer Superconducting Stripline and Microstrip Transmission Lines**," (D. Nghiem, J. T. Williams, and D. R. Jackson, IEEE Trans. Microwave Theory and Techniques, Vol. MTT-39, pp. 1553-1565, Sept. 1991.

"**Proper and Improper Dominant Leaky Mode Solutions for a Stripline with an Air Gap**," (D. Nghiem, J. T. Williams, D. R. Jackson, and A. A. Oliner), Radio Science, Vol. 28, pp. 1163-1180, Nov.-Dec. 1993.

"**Leakage of Dominant Mode on Stripline with a Small Air Gap**," (D. Nghiem, J. T. Williams, D. R. Jackson, and A. A. Oliner), IEEE Trans. Microwave Theory and Techniques, Vol. 43, pp. 2549-2556, Nov. 1995.

"**The Effect of Substrate Anisotropy on the Dominant-Mode Leakage from Stripline with an Air Gap**," (D. Nghiem, J. T. Williams, D. R. Jackson, and A. A. Oliner), IEEE Trans. Microwave Theory and Techniques, Vol. 43, pp. 2831-2838, Dec. 1995.

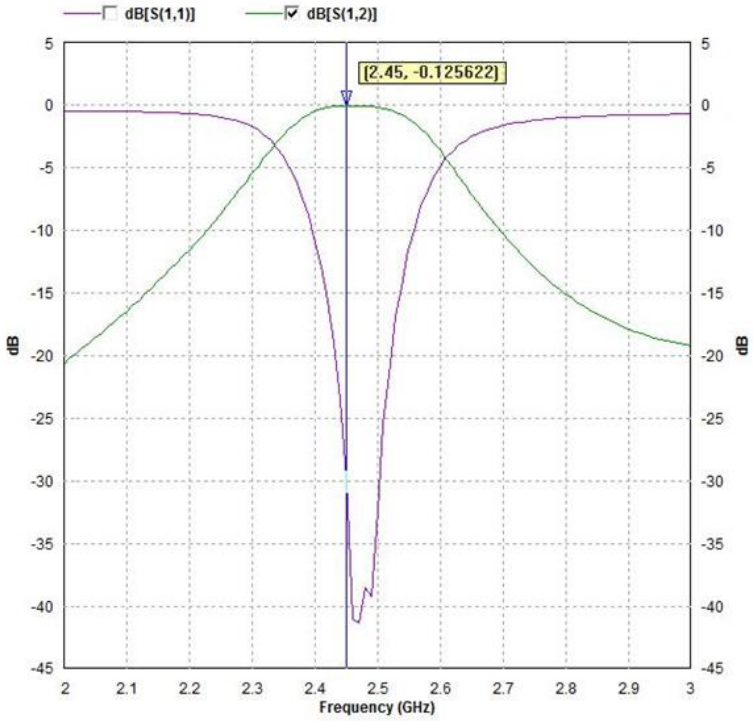
"**Existence of a Leaky Dominant Mode on Microstrip Line with an Isotropic Substrate: Theory and Measurements**," (D. Nghiem, J. T. Williams, D. R. Jackson, and A. A. Oliner), IEEE Trans. Microwave Theory and Techniques, Vol. 44, pp. 1710-1715, Oct. 1996.

Discussion on 2.45 GHz/60 GHz Contactless Connectors

GWT Wireless Near-field Power-charging System

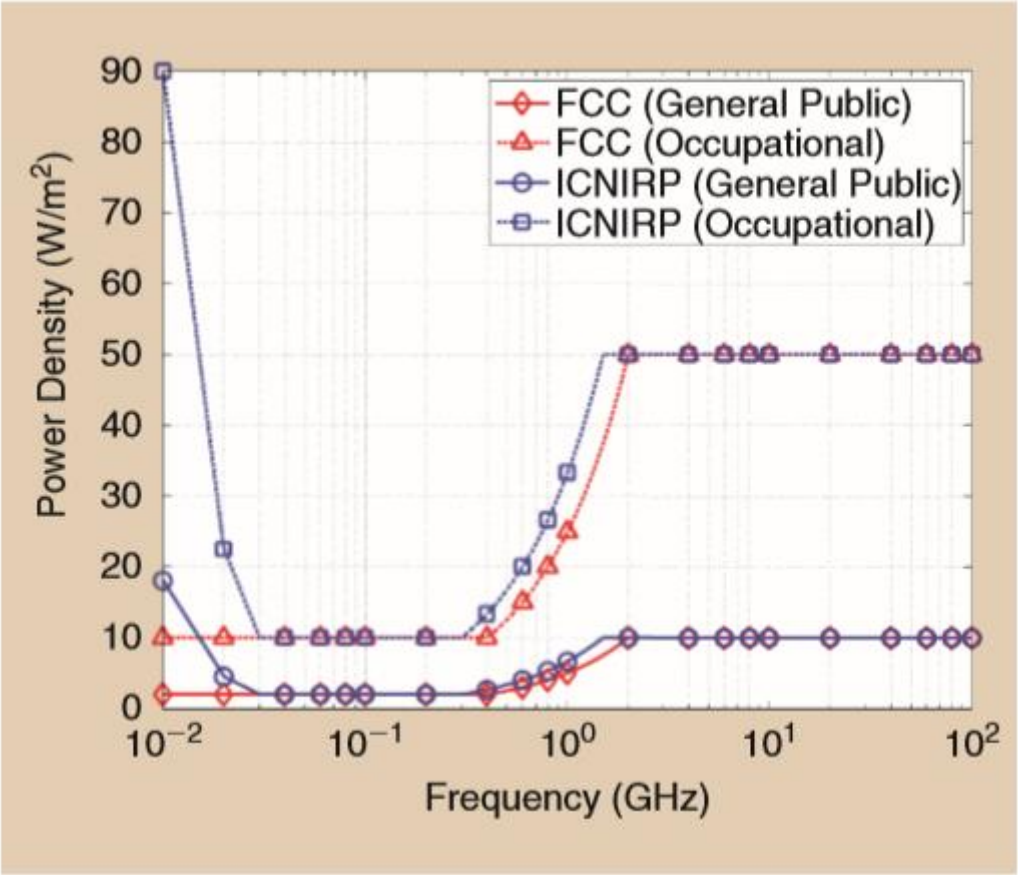
(Conducting Loss & Radiation Loss)

Efficiency = 97% @ 2.45 GHz



GWT Confidential Information

Discussion on Radiation Safety



Discussion on Radiation Safety

TABLE 1. The variations of exposure limits to RF radiation in several countries.

Country/Guidelines	PD Restrictions for the General Public in W/m²	PD Restrictions for the General Public in mW/cm²	Frequency Range (GHz)	Basis
ICNIRP [17] (1998)	10	1	2–300	Science based
FCC [16] (1996)	10	1	1.5–100	Science based
China [32] (1987)*	0.1	0.01	0.3–300	Science based
Russia [33] (2003)	0.1	0.01	0.3–300	Science based
Switzerland [34] and [35] (2000)*	0.1	0.01	1.8–300	Precautionary
Italy [36] (2003)*	0.1	0.01	0.0001–300	Precautionary
Typical maximum exposure from cellular base station mounted on 50-m tower (assuming a total effective radiated power of 2,500 W in each sector, summed over all channels)	0.01	0.001	1–2	Example from [29]

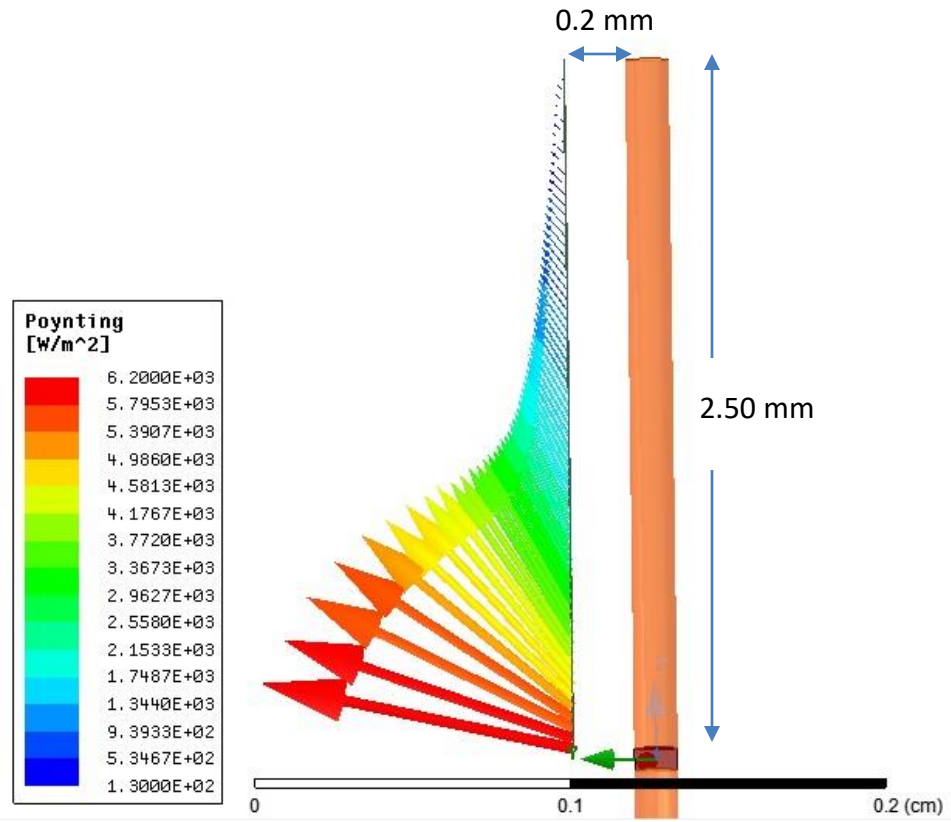
*These restrictions only apply to sensitive areas, such as school, hospital, or rooms in buildings, where they are regularly occupied by persons for prolonged periods.

Discussion on Radiation Safety

Discussion on Radiation Safety

30 GHz Dipole

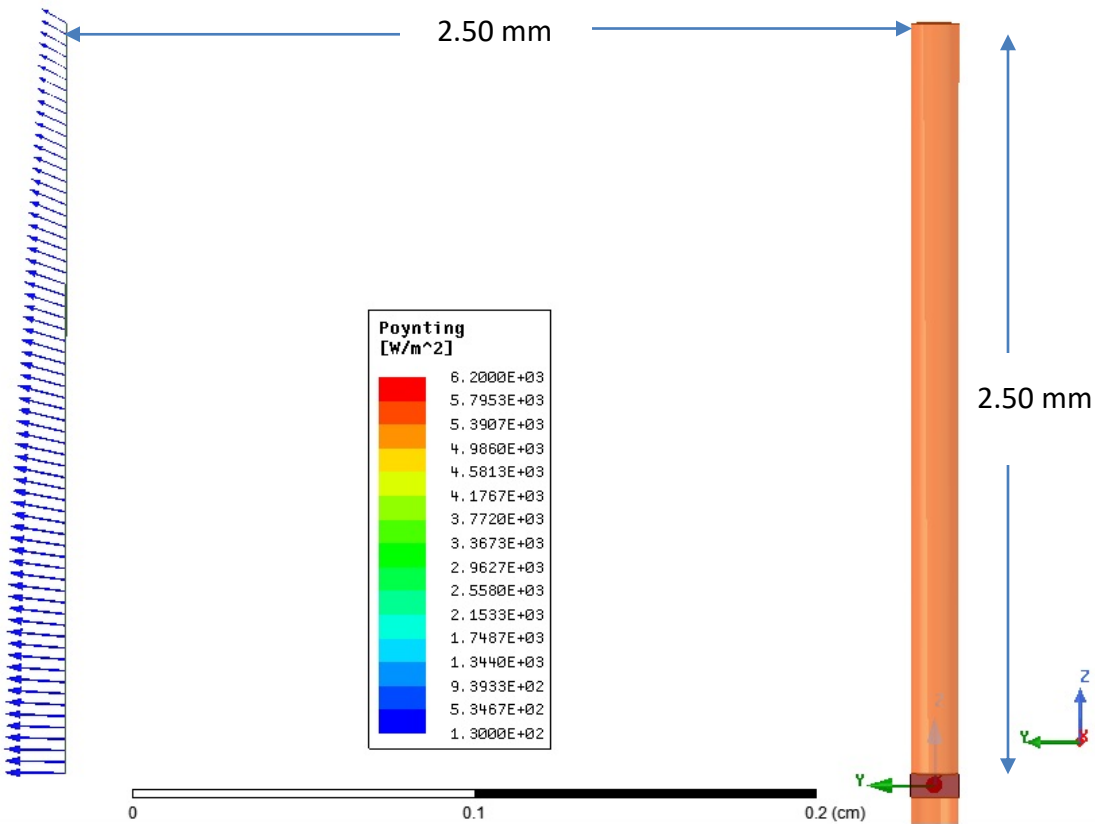
(Transmitting power = 10 mW)



Discussion on Radiation Safety

30 GHz Dipole

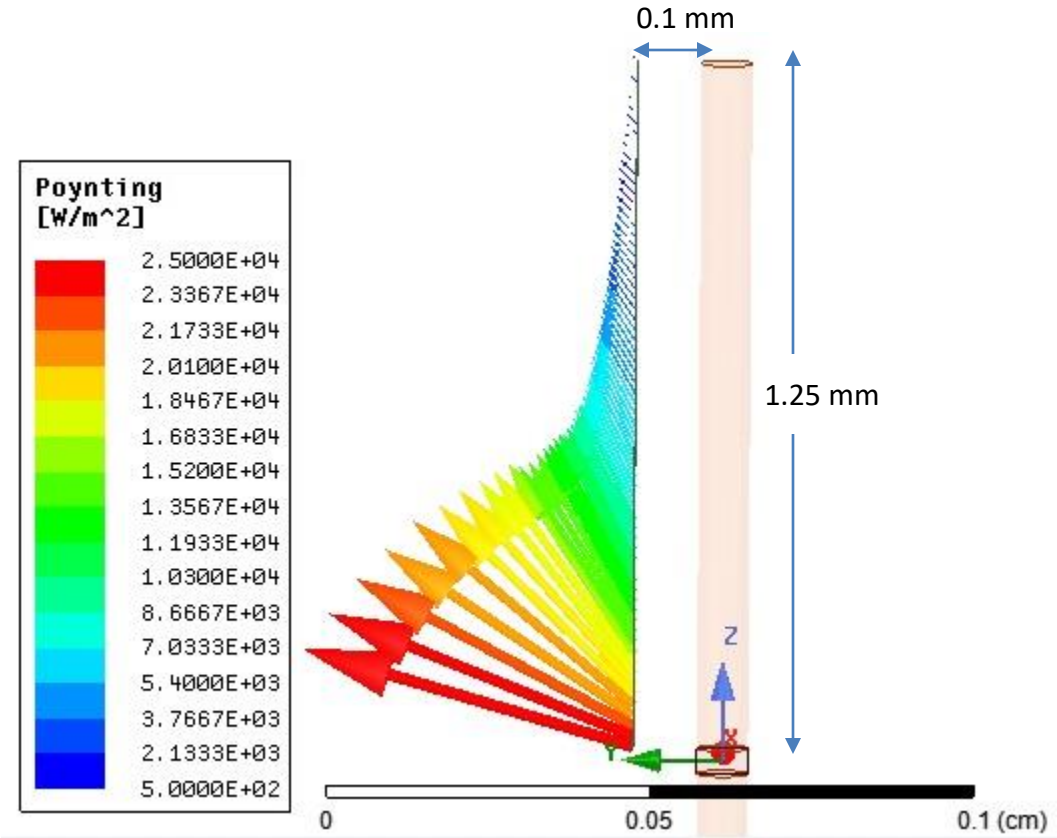
(Transmitting power = 10 mW)



Discussion on Radiation Safety

60 GHz Dipole

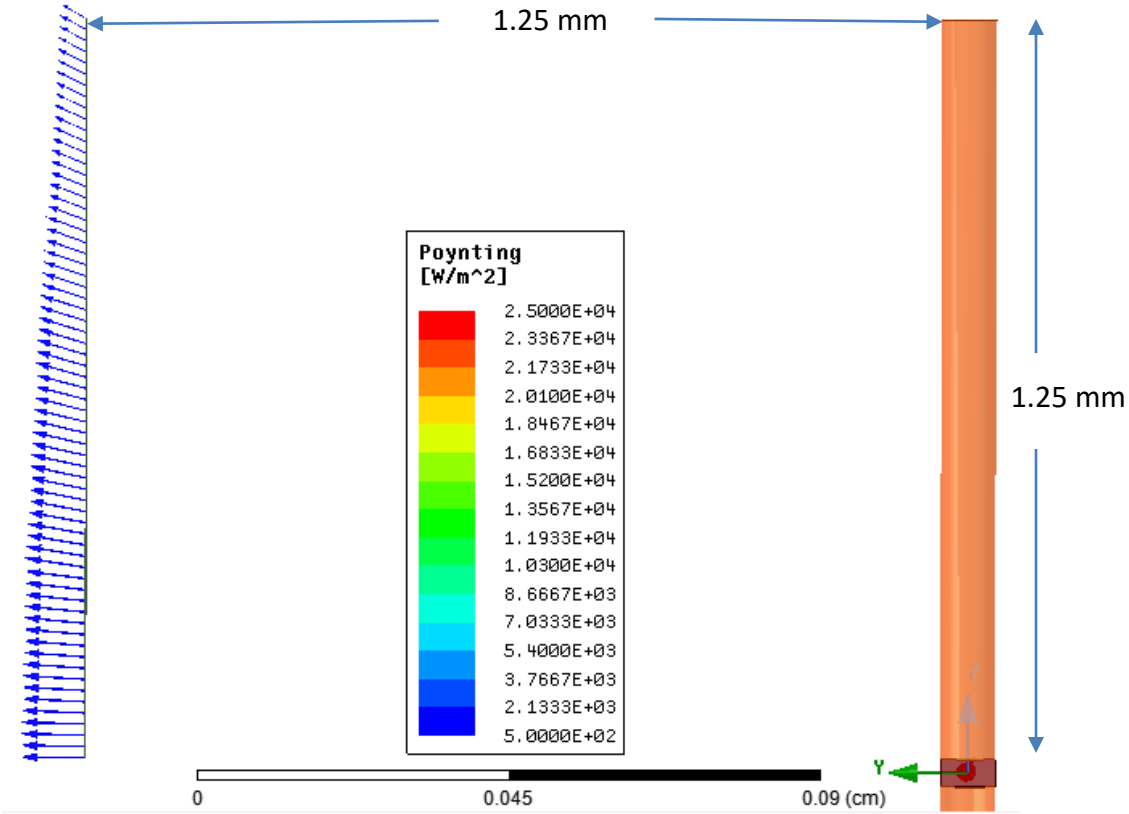
(Transmitting power = 10 mW)



Discussion on Radiation Safety

60 GHz Dipole

(Transmitting power = 10 mW)



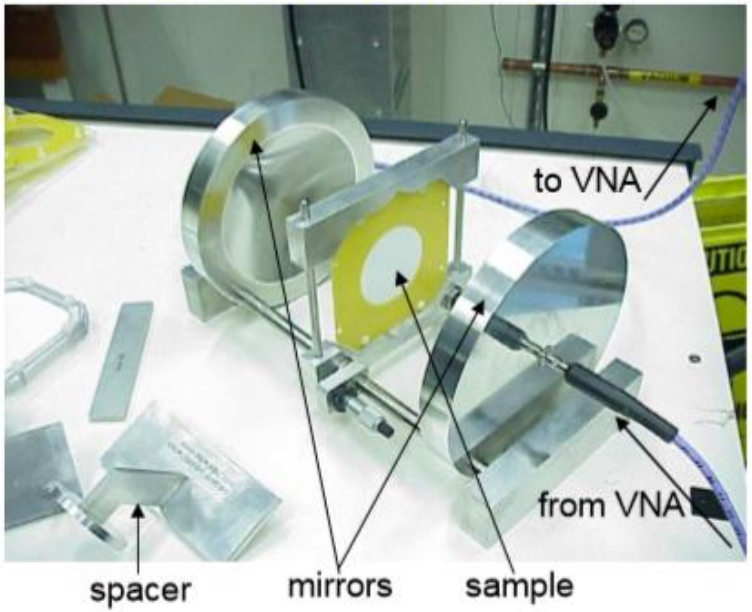
Discussion on 94 GHz Imaging Application

Discussion on Skin Cancer Sensor

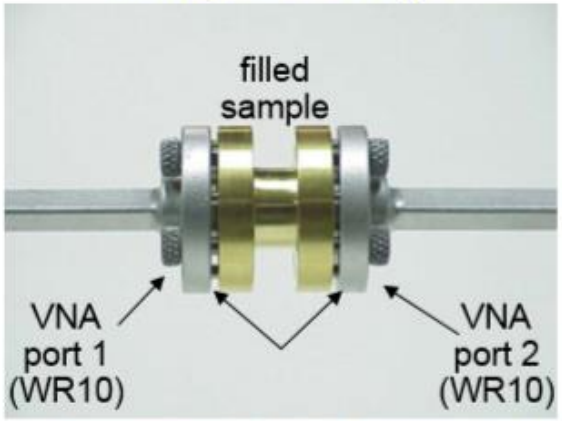
Asymmetrical
Un-even borders
Multiple colors
Larger than ¼ inch

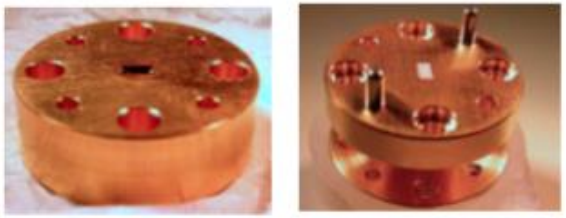
Tissue Characterization

open resonator (20-80 GHz)



waveguide setup





6811 encapsulant teflon

T. Zwick, etc., "Determination of the complex permittivity of packaging materials at millimeter-wave frequencies," IEEE Trans. Microwave Theory Tech., Vol. 54, No. 3, pp. 1001-1010, Mar. 2006.

GWT 60 GHz Skin-Cancer Sensing Parameter

Relative Permittivity	GWT 60 GHz SCSP
4.0	1.47
4.5	3.39
5.0	5.43
5.5	7.59
6.0	9.87
6.5	12.3
7.0	14.8

Q&A

For additional questions, please send an email to DNghiem@GlobalWirelessTechnology.com

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