A Fast Analysis of Electromagnetic Immunity Responses of RF Amplifier Circuit under CW/Digital-Modulation Schemes

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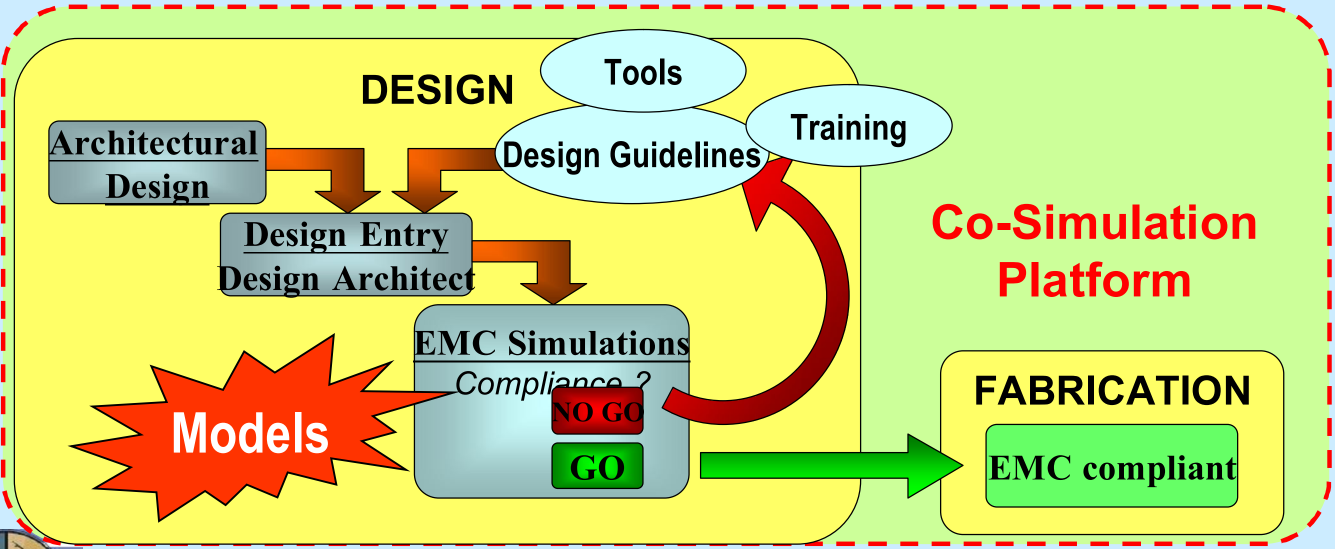
Outline

- Motivation
- Previous Work & Development
- Radiated Susceptibility Macro-Model
- Case Study on the Microstrip Amplifier
  - CW Source
  - BPSK、QPSK、QAM 16 Digital-Modulation Scheme
- Conclusion

Motivation

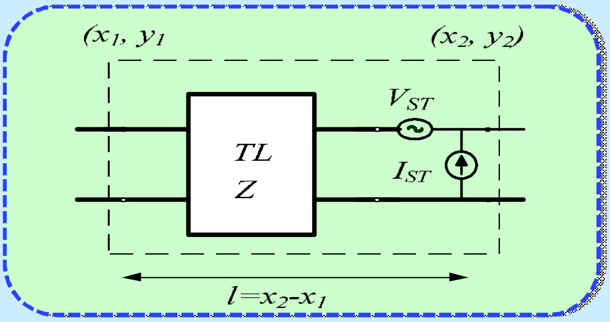
➤ **A Virtual Laboratory.** (EU EMC Directive, 2004)

✓ It's allow to use the appropriate models for computations in order to demonstrate that a product meets the **Regulatory** limits.



Previous Work & Development

Previous Work

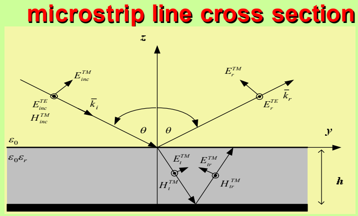


$$V_{ST}(L)=\int_0^L \omega_{11}(L-\tau)\begin{bmatrix}E_z^{inc}(con1,\tau)\\-E_z^{inc}(con0,\tau)\end{bmatrix}d\tau -\left[\int_a^{a'} E_z^{\,i}\cdot d\vec{l}\right]\Bigg|_{z=L}+\omega_{11}(\tau)\left[\int_a^{a'} E_z^{\,i}\cdot d\vec{l}\right]\Bigg|_{z=0}$$

$$I_{ST}(L)=\int_0^L \omega_{21}(L-\tau)\begin{bmatrix}E_z^{inc}(con1,\tau)\\-E_z^{inc}(con0,\tau)\end{bmatrix}d\tau +\omega_{21}(L)\left[\int_a^{a'} E^{\,i}\cdot d\vec{l}\right]\Bigg|_{z=0}$$

Equivalent-source Equation

TE and TM waves incident on the microstrip line cross section



Equivalent Voltage Source

$$V_{ST}(x)=\frac{1}{2}E_0\,F_x(\gamma,\theta,\phi)\left[e^{j\beta L}M_x+e^{-j\beta L}N_x\right]e^{jk_x x_1} +E_0\,F_z(\theta,\phi)\,Q_x\left[\cos(\beta L)-e^{jk_x L}\right]e^{jk_x x_1}$$

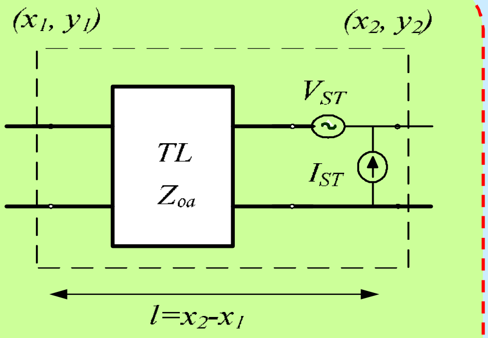
Equivalent Voltage Source

$$I_{ST}(x)=\frac{-1}{2Z_c}E_0F_x(\gamma,\theta,\phi)\left[e^{j\beta L}M_x-e^{-j\beta L}N_x\right]e^{jk_x x_1} -j\frac{1}{Z_c}E_0\sin(\beta L)F_z(\theta,\phi)\,Q_x\,e^{jk_x x_1}$$

[Ref.] C. R. PAUL, "Analysis of Multi-conductor Transmission lines" Second Edition, 2008

Radiated-Susceptibility Simulation Model

The key steps in facilitating this fast method may be summarized in the following :



Radiated-Susceptibility Macro Model

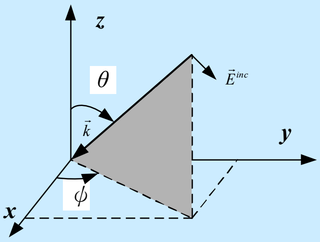
- ✓ For each microstrip-line element, the parameters associated with the location (*xi*, *yi*) of the microstrip, and the incident plane wave are first substituted into the analytical equivalent source expressions so that one may calculate the field-induced equivalent sources (*Vi, Ii*) across the terminals of each microstrip element.
- ✓ By incorporating these equivalent-source expressions for all microstrip elements into the ADS circuit solver, and then combining these equivalent sources with the excitation sources of the circuit, one may use the same circuit solver to simulate the output terminal voltages and currents of the whole circuit.

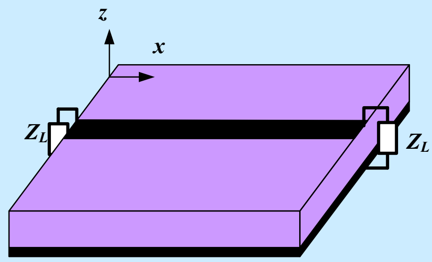
[Ref.5] H. C. Hsieh, C. N. Chiu, M. S. Lin, C. H. Wang, and C. H. Chen, "An equation-based hybrid method for predicting radiated susceptibility responses of RF/Microwave circuits," IEEE Trans. on Electromagn. Compat., vol.53, no. 2, pp. 339-348, May 2011.

Radiated Susceptibility_

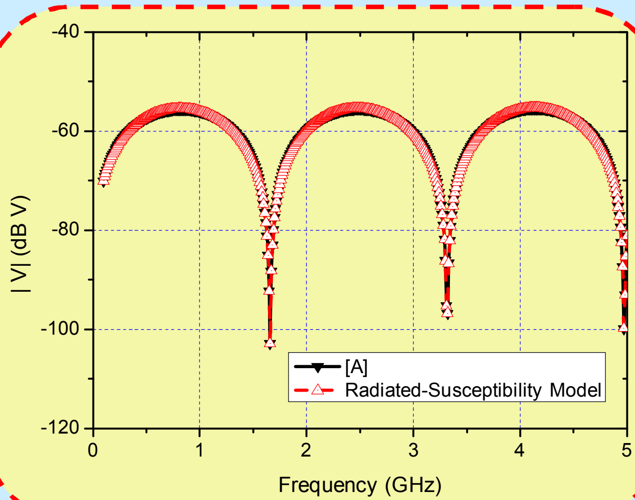
Single Microstrip Line (θ=0°)

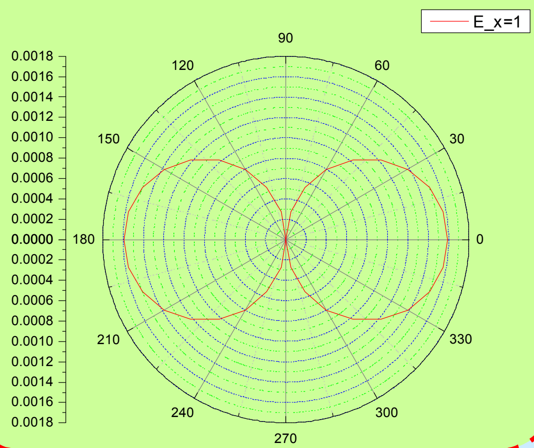
- E_0=1 V/m
- $\gamma = \theta = \varphi = 0^\circ$





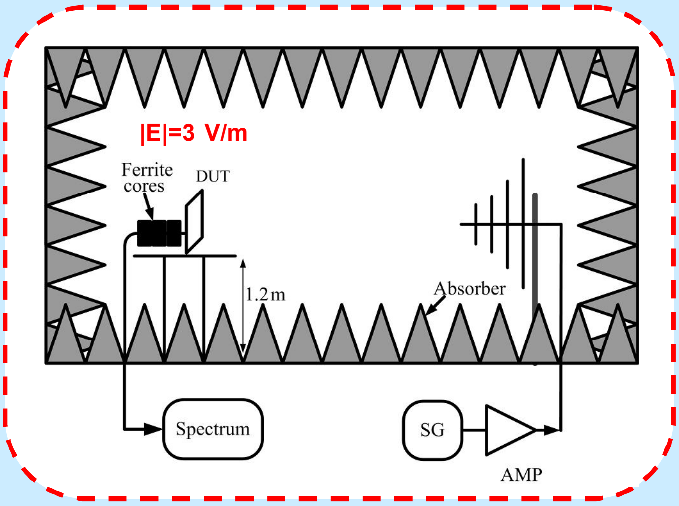
***Z*=50 Ω**
***h*=1.5 mm,**
***w*=1 mm,**
***l*=10 cm**

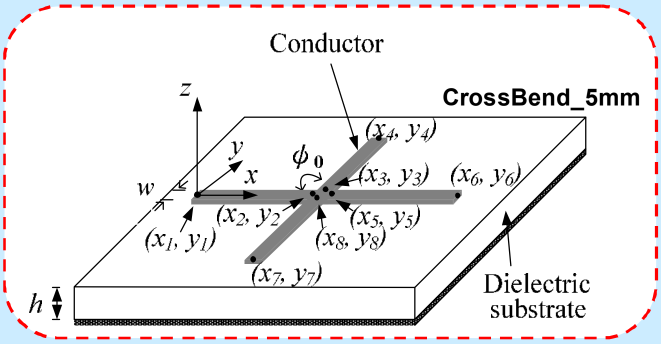


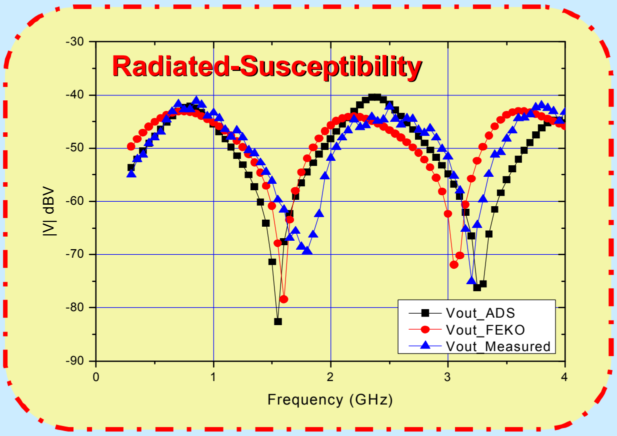


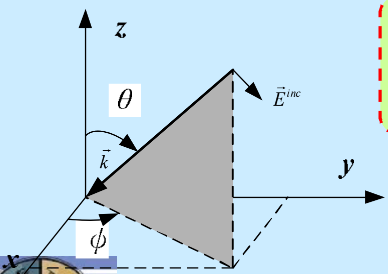
[Ref. A] M. Leone, and H. L. Singer, "**On the Coupling of an External EM Field to a PCB Trace**," IEEE Trans. On EMC, 1999

Radiated Susceptibility_
Measurement & Simulation





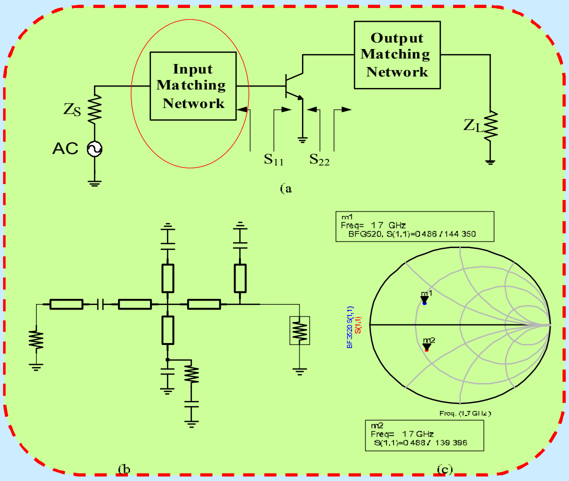




E_0 = 3 V/m, $\gamma = \theta = \phi = 0^\circ$. ($ZL1 = ZL2 = ZL3 = ZL4$ = 50 Ω). X-polarization

εr = 4.6, h = 1.6 mm, w = 5 mm, $l1 = l2 = d1 = d2$ = 5 cm

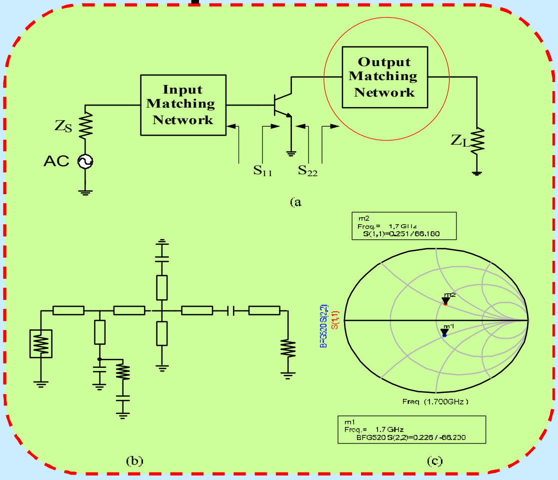
Case Study on a Microstrip Amplifier_Design Technique



Matching Network

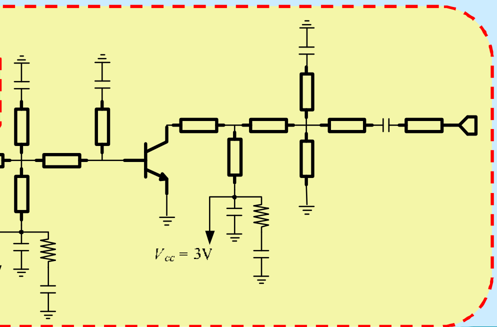
f_o=1.7 GHz

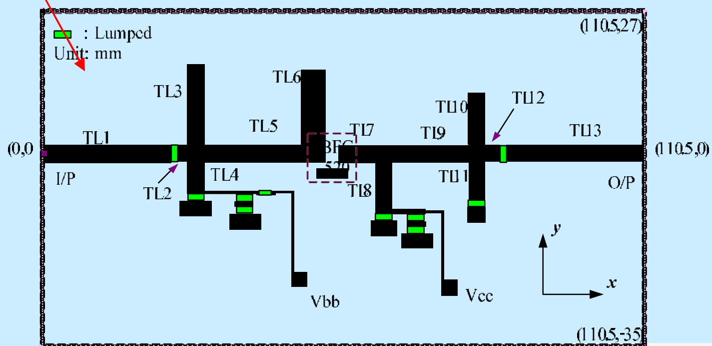
Gain>10 dB



Layout of the amplifier on PCB

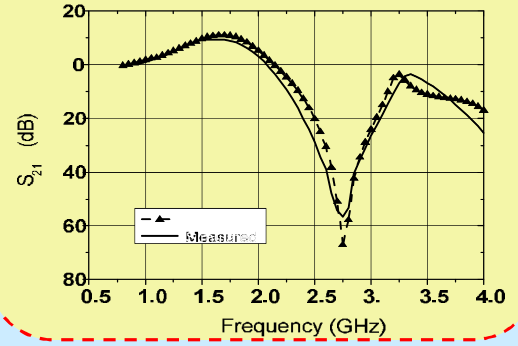
Schematic of the single-stage

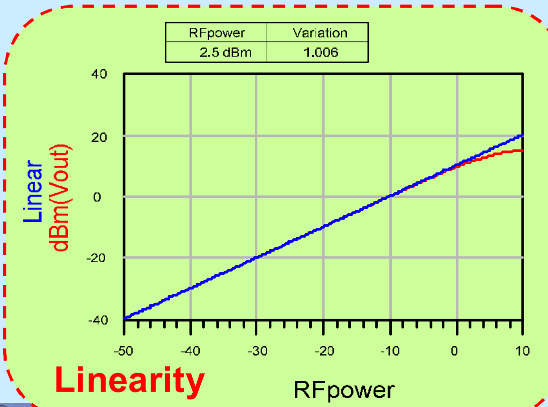




Performance of the Microstrip Amplifier

S-Parameters



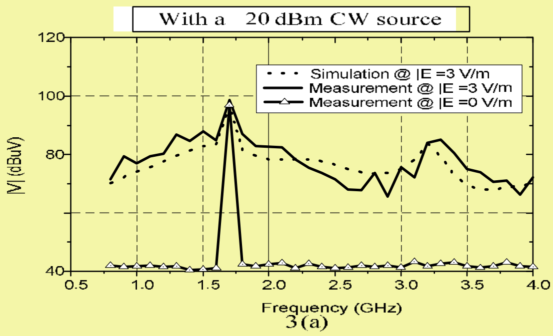


Linearity

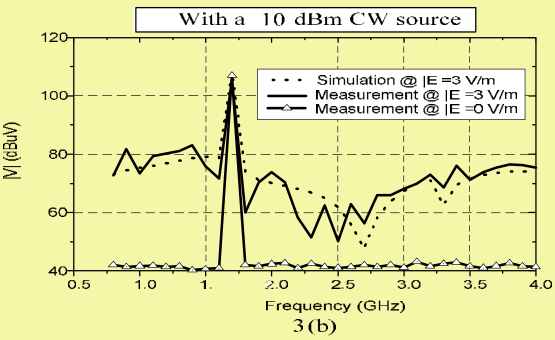
Geometric Parameters

Item	Width	Started point	Terminated point
TL 1	3.16	(0, 0)	(24, 0)
TL 2	3.16	(25, 0)	(28, 0)
TL 3	3.16	(29, 1.6)	(29, 16.6)
TL 4	3.16	(29, -1.6)	(29, -7.6)
TL 5	3.16	(30, 0)	(48, 0)
TL 6	4.5	(50, 1.6)	(50, 15.6)
TL 7	3.16	(55, 0)	(62, 0)
TL 8	3.16	(67, -1.6)	(67, -10.4)
TL 9	3.16	(70, 0)	(84, 0)
TL 10	3.16	(80, 1.6)	(80, 11.1)
TL 11	3.16	(80, -1.6)	(80, -8.7)
TL 12	3.16	(82, 0)	(85, 0)
TL 13	3.16	(86, 0)	(111.5, 0)

Radiated-Susceptibility Responses of RF Amplifier



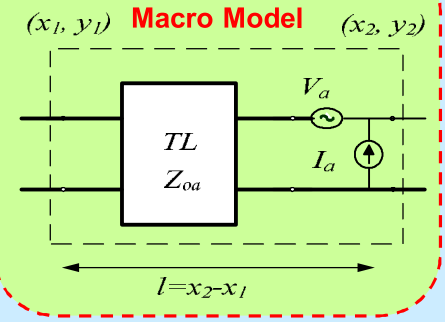
3 (a)

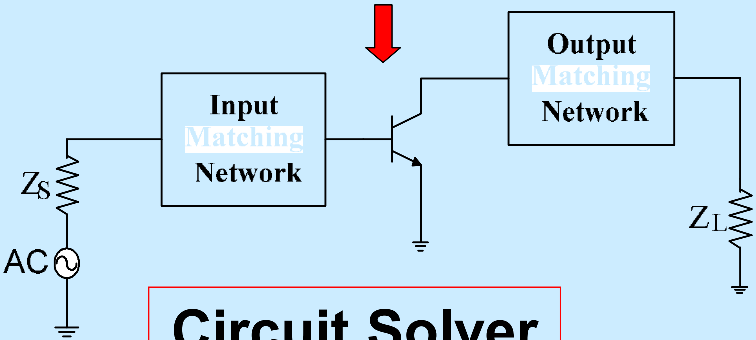


3 (b)

Single-Stage Amplifier

Radiated-Susceptibility Macro Model

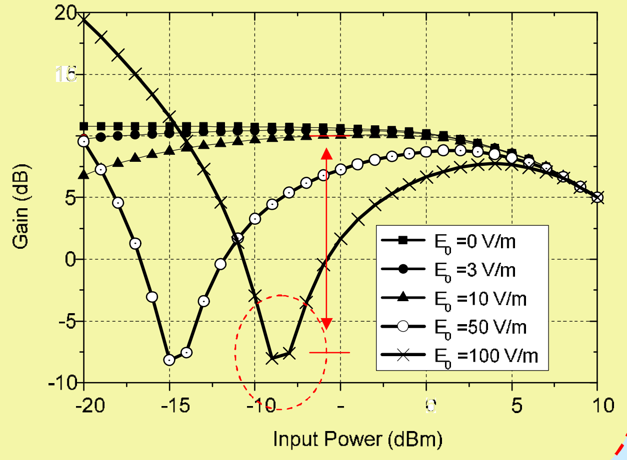




Circuit Solver

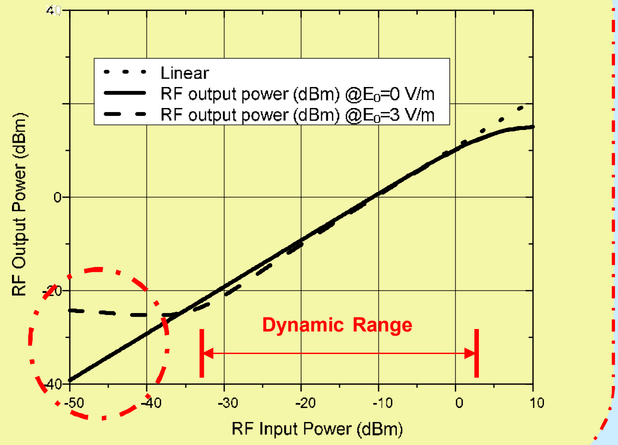
Radiated-Susceptibility Responses of RF Amplifier

Gain



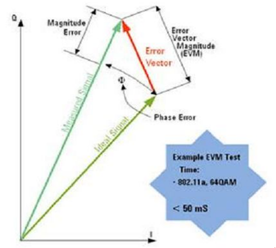
Output gain is degraded more than **18 dB**

Linearity (E_0=3 V/m)

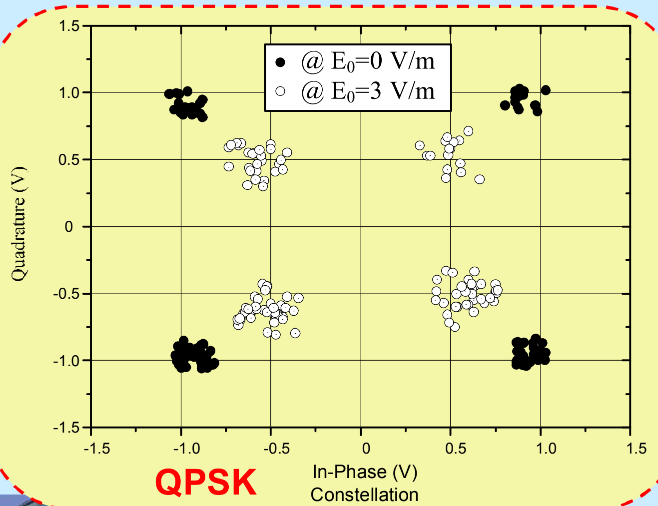


E_0 = 3 V/m, $\gamma = \theta = \phi = 0^\circ$. ($ZL$ = 50 Ω). X-polarization

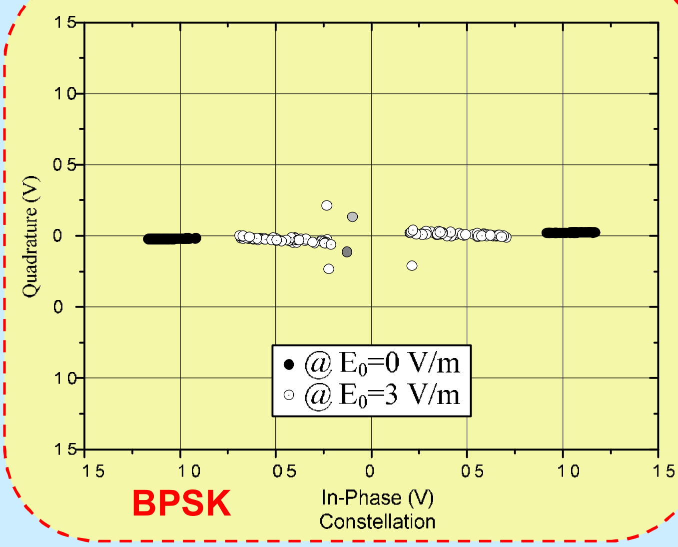
Radiated-Susceptibility Responses of RF Amplifier



$$EVM_{rms} = \sqrt{\frac{\sum_i |Z_i - S_i|^2}{\sum_i |S_i|^2}}$$



QPSK



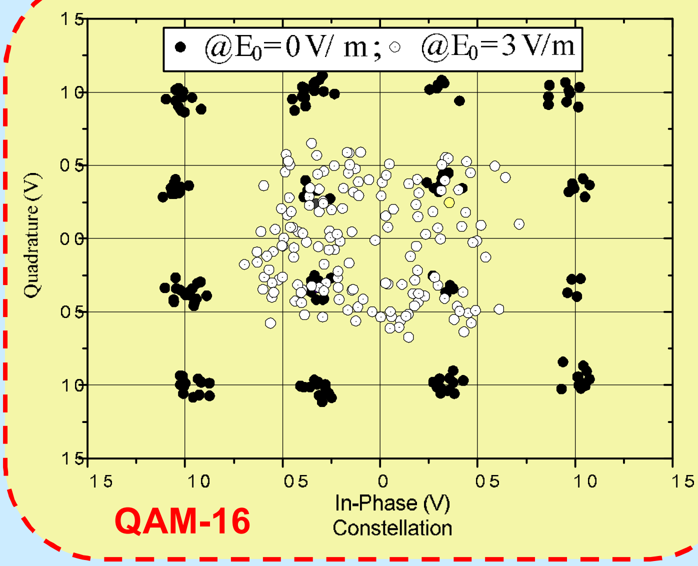
BPSK

Source : -10 dBm, 2 Mb/s, f_c=1.7 GHz

E_0=3 V/m @ 1.701 GHz

Radiated-Susceptibility Responses of RF Amplifier

	EVM_{rms}	
	E_0=0 V/m	E_0=3 V/m
QPSK	5.8 %	14.8 %
QAM 16	6.5 %	16.3 %
QAM 32	8.8 %	15.9 %
QAM 64	5.7 %	13.4 %



Since the locations of signals have been Mixed up, the demodulation of amplifier QAM16 signals would be quite difficult or even impossible.

Conclusions

- The Radiated-Susceptibility Responses of the Microstrip Amplifier has been calculated by the Equation-Based circuit solver.

- The constellation signals of the digital-modulated RF amplifier **With** and **Without** external wave illumination are investigated.

- The developed method provides a **Simple** and **Quick** way to predict the Radiated-Susceptibility Responses of RF Amplifier circuit.

Thanks for your attention!