

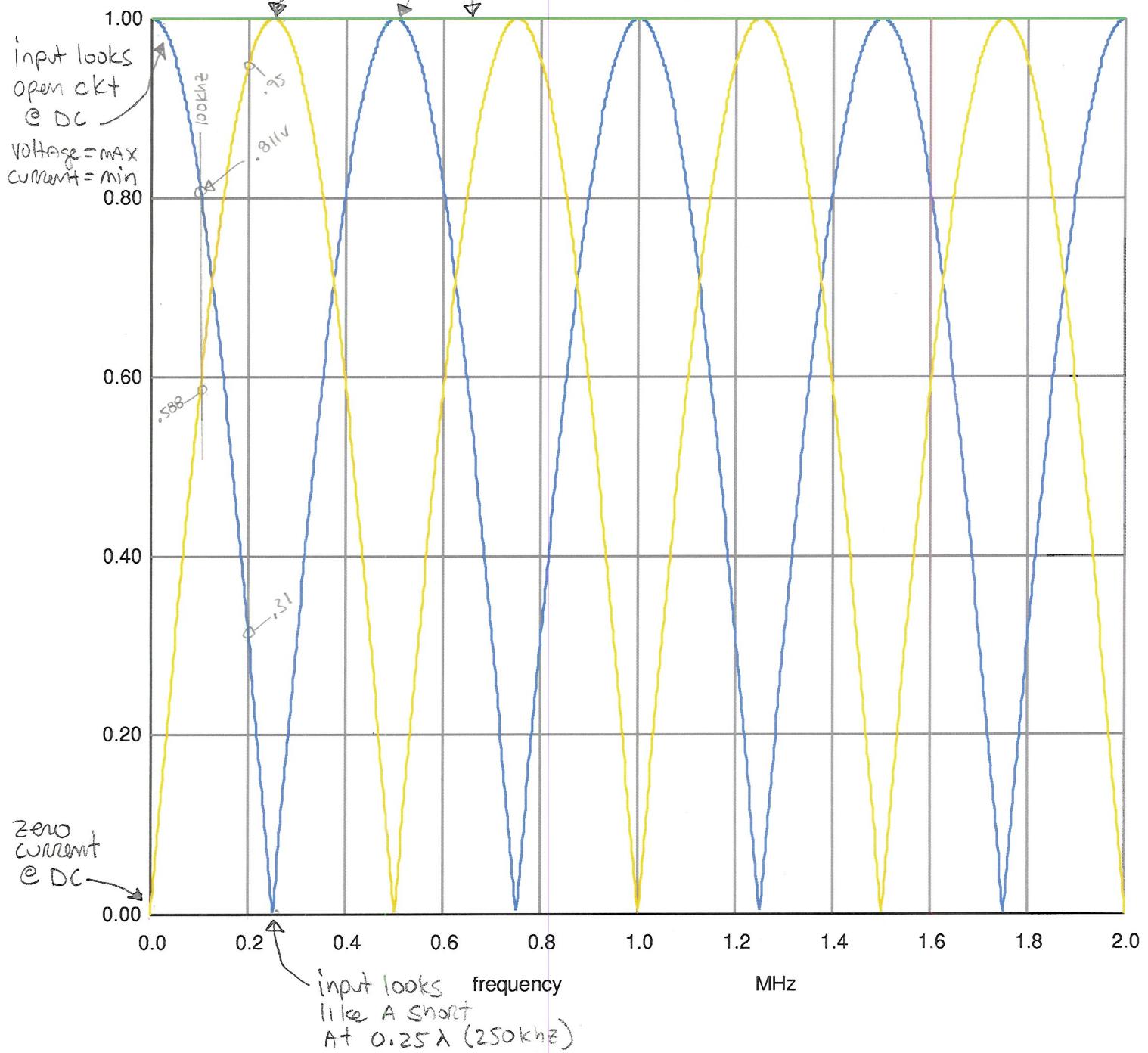
(A 300m line with  $v_p=c$ )  
is  $1 \lambda \approx 1\text{MHz}$ .

Pattern repeats every  $\frac{\lambda}{2}$   
Always 1Vpp at the output at any freq

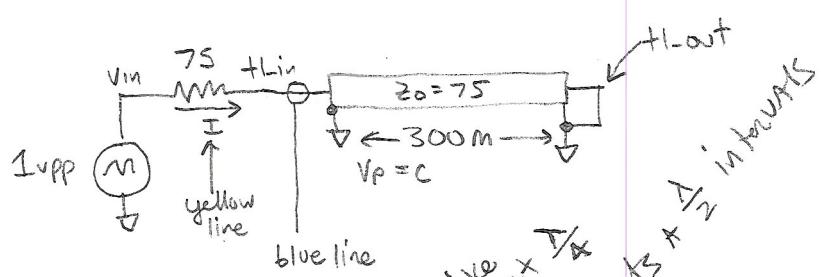
$|V|$

—  $vm(t_{l\_in})$   
—  $vm(t_{l\_out})$

—  $vm(v_{in})$   
—  $vm(v_{in}, t_{l\_in})$  (scaled current measurement)

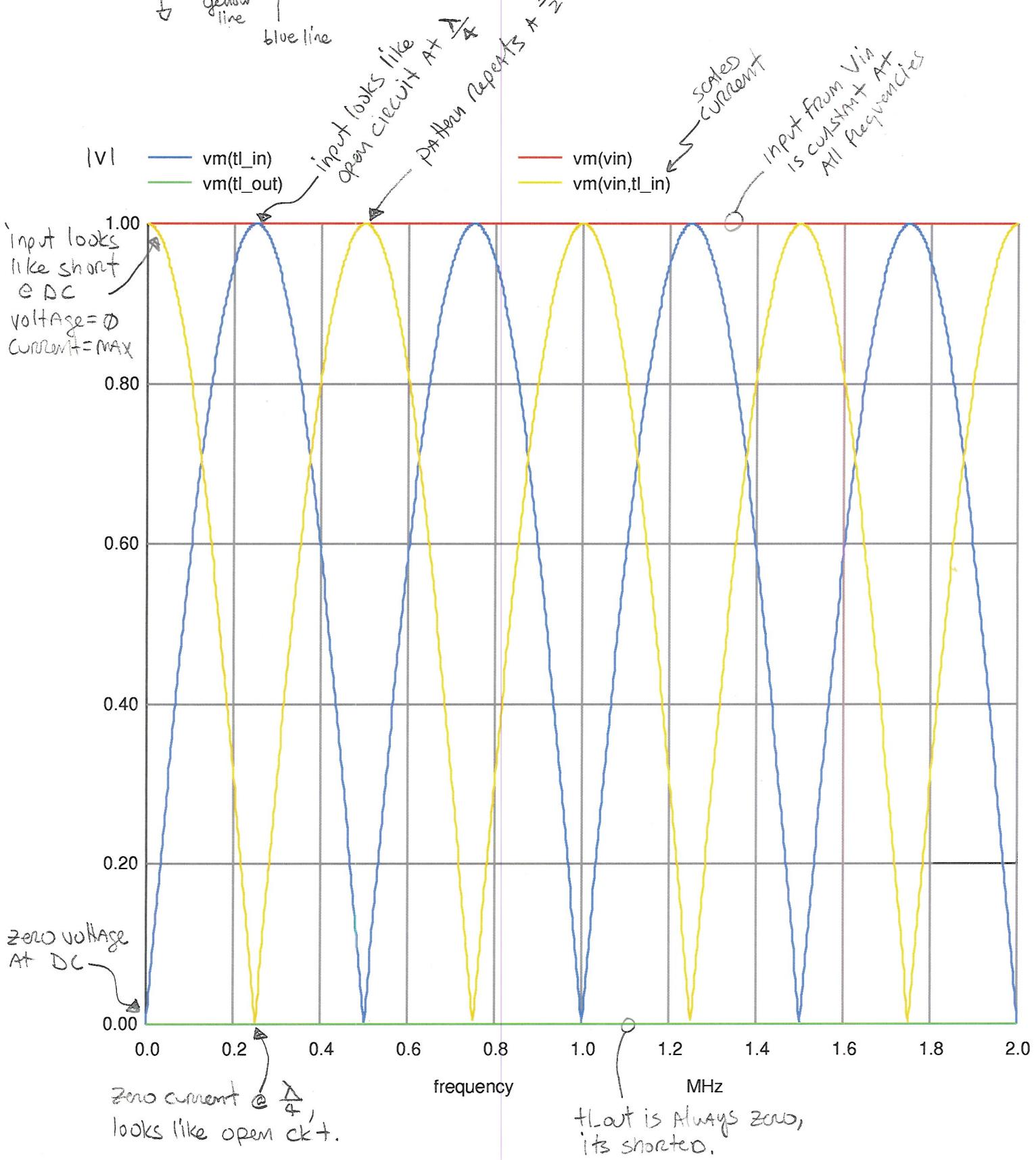


standing.sp(c) [line shorted @ end]



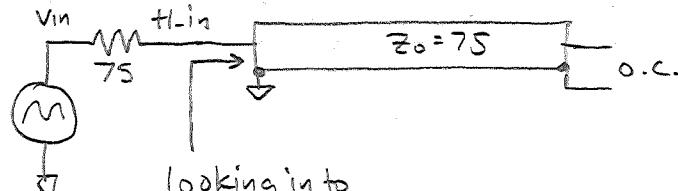
$$\frac{1}{1\mu s} = 1 \text{ MHz}$$

A  $1\mu s$  line is  $\frac{1}{4}$  at 250kHz



## Steady State Excitation - pt 2

Referring to Standing.sp (b)



looking in to  
the T-line...

- @ DC.  $I=0, V=\text{max}$
- @ 200kHz  $I=\text{max}, V=0$
- @ 100kHz ??

$$\text{@ 100kHz } V(V_{in}, +\text{L-in}) = 0.588$$

$$I_{in} = .588/75 = 7.84 \text{ mA}$$

$$\begin{aligned} |Z_{in}| &= \frac{|V_{in-in}|}{|I_{in}|} = \frac{.811}{.00784} = \underline{103.4 \Omega} \\ (\text{magnitude}) &\quad R \left( \frac{.588}{75} \right) \end{aligned}$$

Open ckt xformed to  $103\Omega$

$$\text{@ 200kHz } V(V_{in}, +\text{L-in}) = 0.95$$

$$I_{in} = \frac{.95}{75} = 12.67 \text{ mA}$$

$$\begin{aligned} |Z_{in}| &= \frac{|V_{in-in}|}{|I_{in}|} = \frac{.315}{12.67 \text{ mA}} = \underline{24.47 \Omega} \\ (\text{magnitude}) & \quad \text{open ckt xformed to } 24.47 \Omega \end{aligned}$$

Standing waves give us the ability to transform impedances.

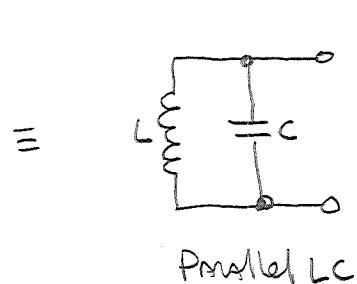
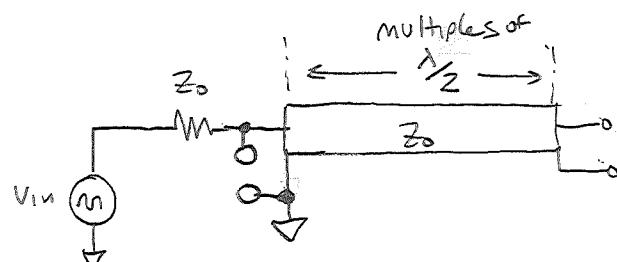
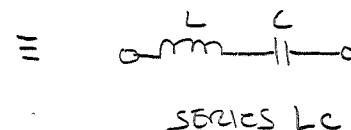
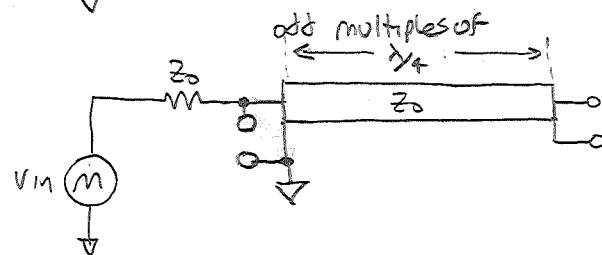
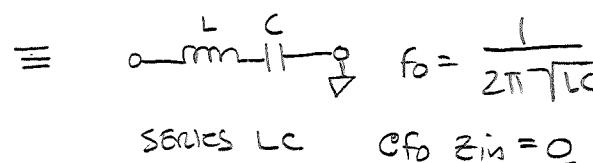
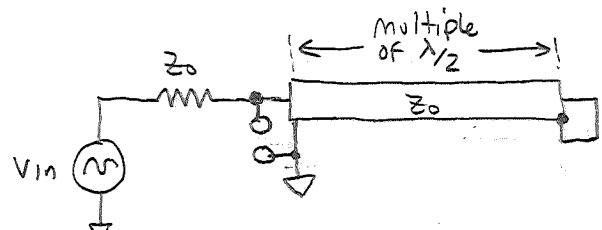
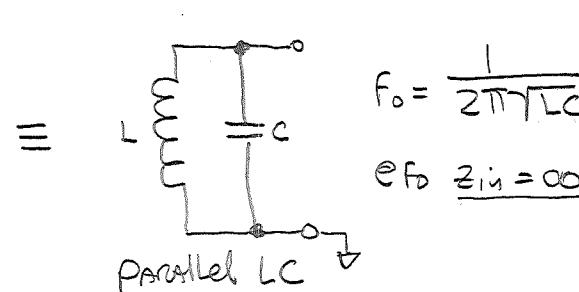
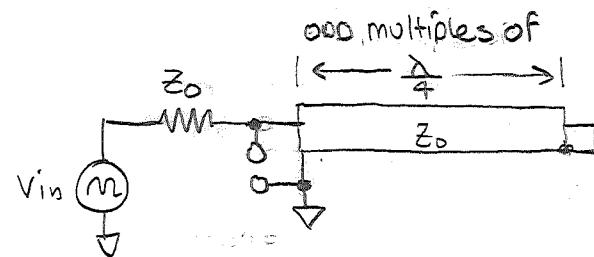
Impedance here is the  $\frac{|V_{in}|}{|I_{in}|}$  relationship at the T-Line input

So, the  $Z_{in}$  of a mismatched T-Line in S.S. AC excitation depends upon:

- electrical length
- frequency of operation
- $Z_{LOAD}$

## Steady State Excitation - Pt 2

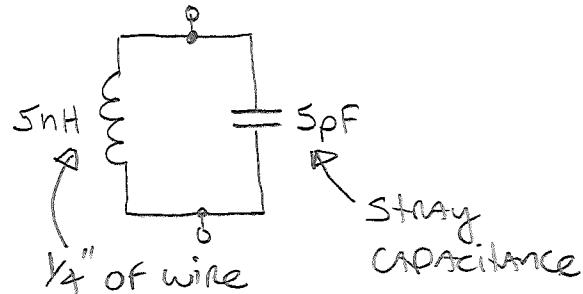
### Resonant Structures formed by T-Lines



## Steady State Excitation - Pt 2

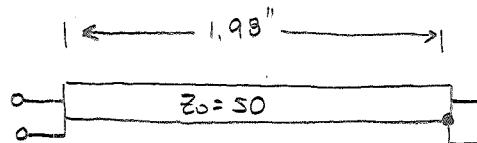
The resonant behavior of T-Lines allow construction of very high frequency "tank" circuits that would be extremely difficult to otherwise construct.

Ex. 1GHz parallel resonant circuit



impractical

OR



easily constructed

$$v = 0.8c$$

$$l = \frac{1.8c}{1 \times 10^9} = .2m = \lambda$$

$$\frac{\lambda}{4} = .05m \text{ or } \underline{\underline{2''}}$$

## High Frequency Design

### CLASS E AMPLIFIER

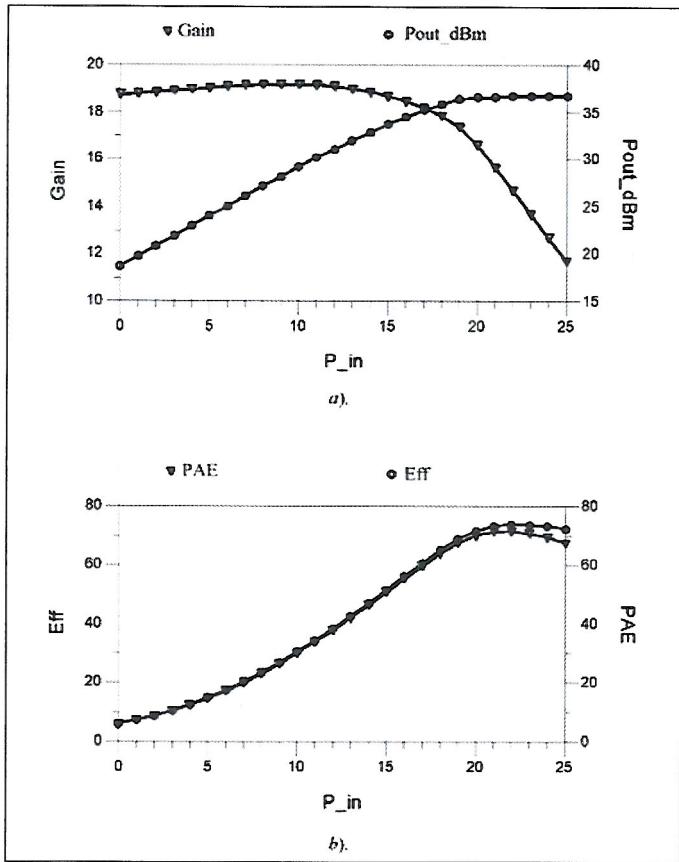


Figure 6 . Simulated results for Class E GaN HEMT power amplifier.

line Class-E load network shown in Figure 2.

Figure 6 shows the simulated results of a transmission-line Class E power amplifier using a RO4350 30-mil substrate. The maximum output power of 37 dBm, drain efficiency of 73% and power-added efficiency (PAE) of 71% at the center bandwidth frequency of 2.14 GHz are achieved with a power gain of 14 dB (linear gain of 19 dB) and a supply voltage of 25 V.

#### Implementation and Test

The transmission-line Class E power amplifier was fabricated on a RO4350 30-mil substrate. Figure 7 shows the test board of this power amplifier using a 5 W GaN HEMT NPTB00004 device. The input matching circuit, output load network, and gate and drain bias circuits (with bypass capacitors on their ends) are fully based on microstrip lines of different electrical lengths and characteristic impedances, according to the simulation setup shown in Figure 5.

Figure 8 shows the measured results with a maximum output power of 37 dBm, a drain efficiency of 70%, and a PAE of 61.5% with a power gain of 9.5 dB at the operating frequency of 2.14 GHz (gate bias voltage  $V_g = -1.4$  V,

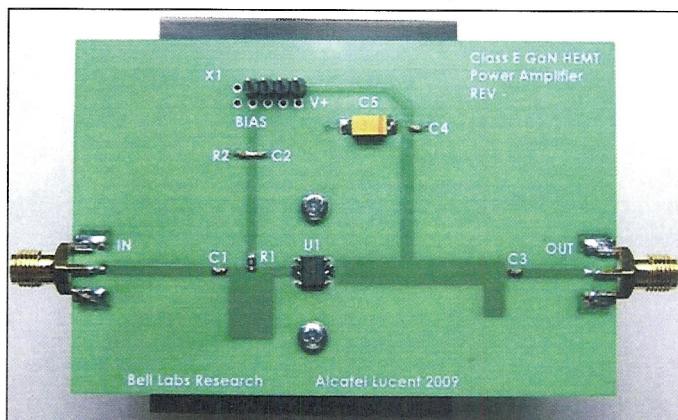


Figure 7 . Test board of Class E GaN HEMT power amplifier.

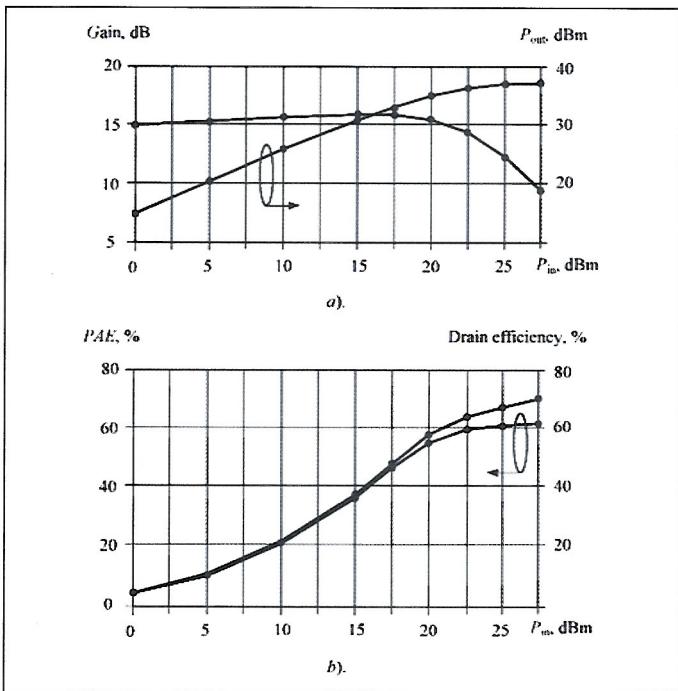


Figure 8 . Measured results for Class E power amplifier at 2.14 GHz.

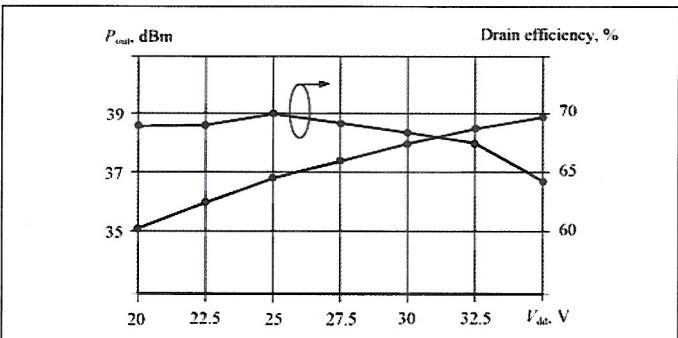
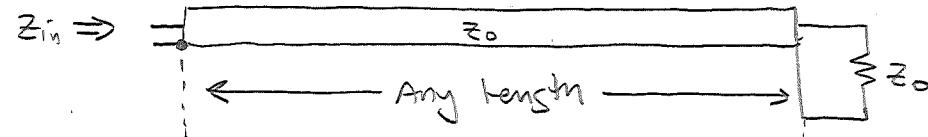


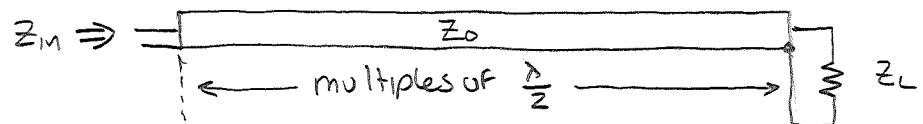
Figure 9 . Measured output power and drain efficiency versus supply voltage.

## Steady State Excitation - pt 2

Keep in Mind:



Any T-line, terminated in its  $z_0$  has  $Z_{in} = z_0$  for any length and at any frequency.



Any line a multiple of  $\frac{\lambda}{2}$  has an input impedance equal to  $z_L$  including complex impedances  
 $(z_L = R \pm jX)$

At lengths other than  $\frac{\lambda}{4}$  multiples, the T-line can look like L or C.