

## THE END OF LINE TAIL BITER

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**Summary.** It is well known that the fall time of a pulse generated by means of a Pulse Forming Line (PFL), of either the distributed or lumped parameter type, is longer than the rise time by approximately a, rule of thumb, factor of two. The reason for this lengthening of the fall time is the result of the wave reflected back on the line during the rise time, which is then again reflected from the far end of the line and propagates to the load end where it affects the fall time of the pulse to the load. If a switch and termination is placed at the far end of the PFL and the switch is synchronized to close when the reflection from the load end of the line arrives, then it is possible to affect the pulse fall time. By choosing the value of the termination the fall time can be adjusted over a range from about twice the rise time to a speed which is much faster, typically about 40 percent of the rise time.

**Analysis.** For purposes of analysis it will be assumed that the model is as shown in Fig. 1. Here an ideal transmission line is shown with a switch and a rise time "spoiling" filter connected to a load. The spoiling filter represents whatever in the way of a component acts to account for the degradation of the rise time. That is the actual degradation of rise time from the ideal PFL may be due to either the construction of an actual PFL with lumped components and/or external strays due to the switch and/or load. In any case, the "spoiling" filter is used to account for the rise time in the model. For simplicity, only two cases will be considered for the spoiling filter; a shunt capacitance or a series inductance. Initially, with the switch still open, the transmission line is charged to a voltage  $V_0$  which is represented as a standing wave. The PFL is open circuited at both ends and equal and opposite TE waves travel on the PFL such that, at any point, their sum is  $V_0$ . The amplitudes of the waves are each  $V_0/2$ . The voltage reflection coefficient at the open ends is 1, so the waves simply turn around when they reach the end and the standing wave remains stationary as long as there are open circuits at each end of the PFL. When the switch is closed the reflection coefficient no longer remains at 1 and both the transmitted and reflected waves become functions of the time varying reflection coefficient. With a shunt capacitor as the spoiling filter there is an initial short circuit when the switch closes and the reflection coefficient is minus one. With a series inductor the initial reflection coefficient is still plus one but decays as the load current builds up. The analytical expressions for the rise of the load voltage and the waveform of the reflected voltage for both cases of spoiling filters are:

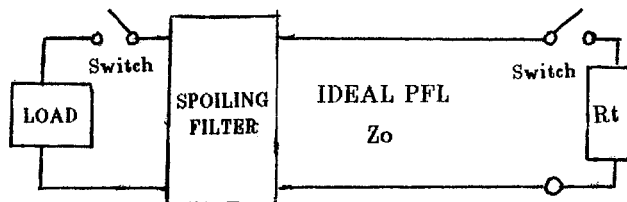
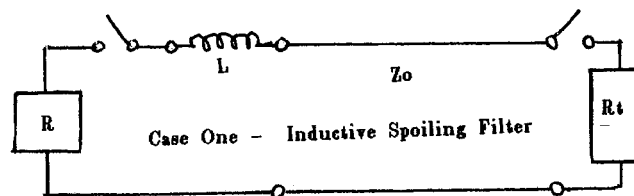
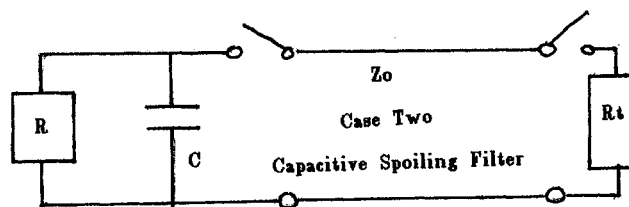


Fig. 1 - Circuit Model for Analysis



$$(1) \quad V_L(t) = V_0 \cdot (R/(R+Z_0)) \cdot (1 - \text{Exp}(-t \cdot R/L))$$

$$(2) \quad V_R(t) = V_0 \cdot (R/(R+Z_0)) \cdot (\text{Exp}(-t \cdot R/L))$$



$$(3) \quad V_L(t) = V_0 \cdot (R/(R+Z_0)) \cdot (1 - \text{Exp}(-t/(R_P \cdot C)))$$

$$(4) \quad V_R(t) = V_0 \cdot (R/(R+Z_0)) \cdot (-\text{Exp}(-t/(R_P \cdot C)))$$

# Report Documentation Page

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Where:

$V_L(t)$  = load voltage

$V_R(t)$  = reflected voltage

$V_o$  = initial charge voltage of PFL

$Z_o$  = characteristic impedance of PFL

$R$  = load resistance

$R_p = (R Z_o)/(R + Z_o)$

$R_t$  = termination resistance

$L$  = spoiling inductance

$C$  = spoiling capacitance

$$(6) \quad V_L(t) = V_o * R / (R + Z_o)^*$$

$$\begin{aligned} & ((1 - 2 * \text{Gamma} * R / Z_o) * \text{Exp}(-t * (R + Z_o) / L) \\ & + 2 * \text{Gamma} * R / Z_o * \text{Exp}(-t * R / L)) \end{aligned}$$

$$(7) \quad V_L(t) =$$

$$V_o * R / (R + Z_o) * \text{Exp}(-t / (C * Z_o)) * (1 - 2 * \text{Gamma} * t)$$

In both cases, the reflected voltage propagates toward the far end of the PFL and reflects from the termination with a reflection coefficient which in general is given as Gamma. Thus, the waveform then propagating toward the load end is simply the waveforms given by (2) or (4) multiplied by Gamma. If it is assumed that the pulse is several times longer than the rise time, then the amplitude of the output will stabilize at:

$$(5) \quad V_L(\infty) = V_o * R / (R + Z_o)$$

Then the fall time characteristics will be determined from this level by the delayed waveforms of (2) or (4) multiplied by the far end reflection coefficient, Gamma, as it passes thru the spoiling filter to the load. The results are quite different depending upon which spoiling filter model is used. Equation (6) gives the fall time characteristics for the series inductance filter model and equation (7) for the shunt capacitance filter model.

where:

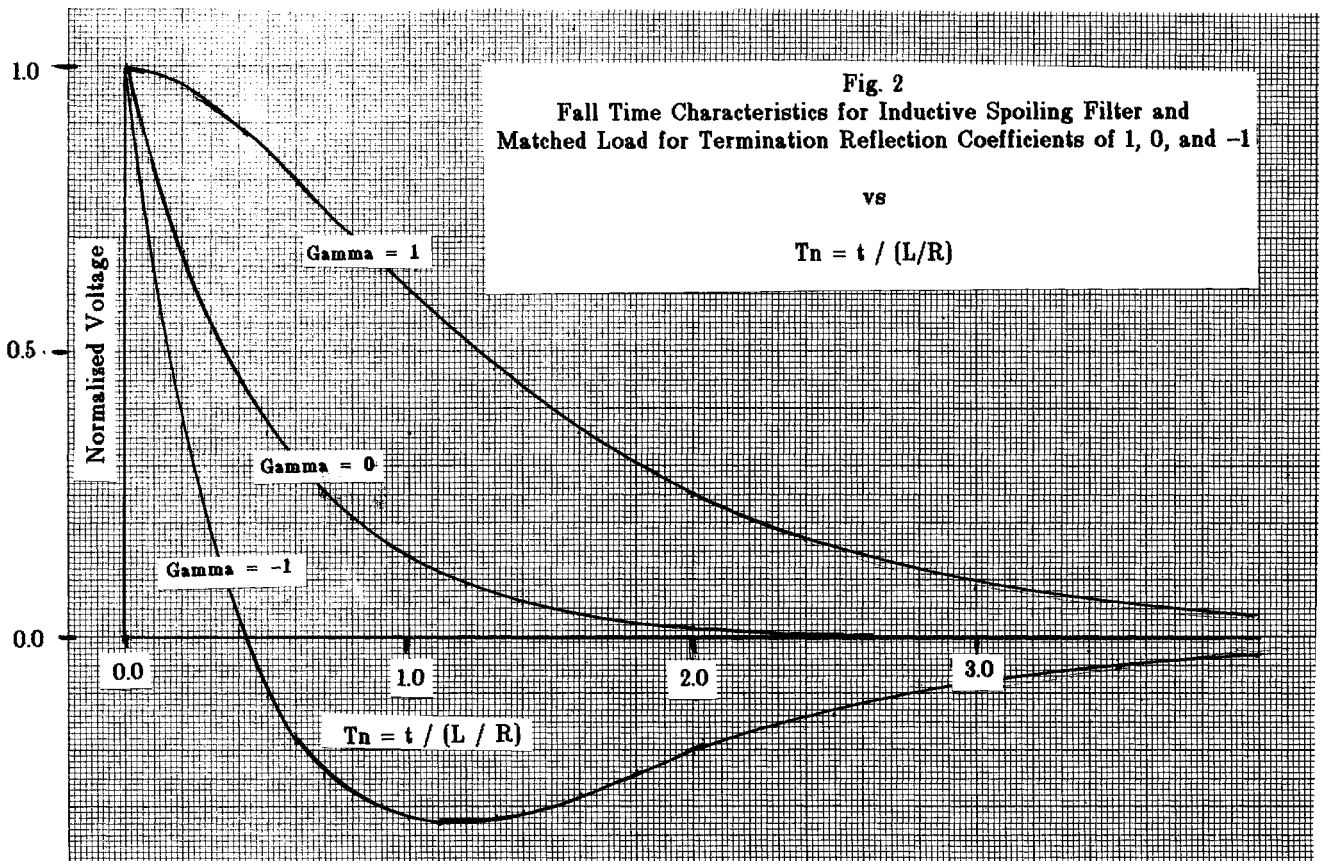
$V_L(t)$  = load voltage

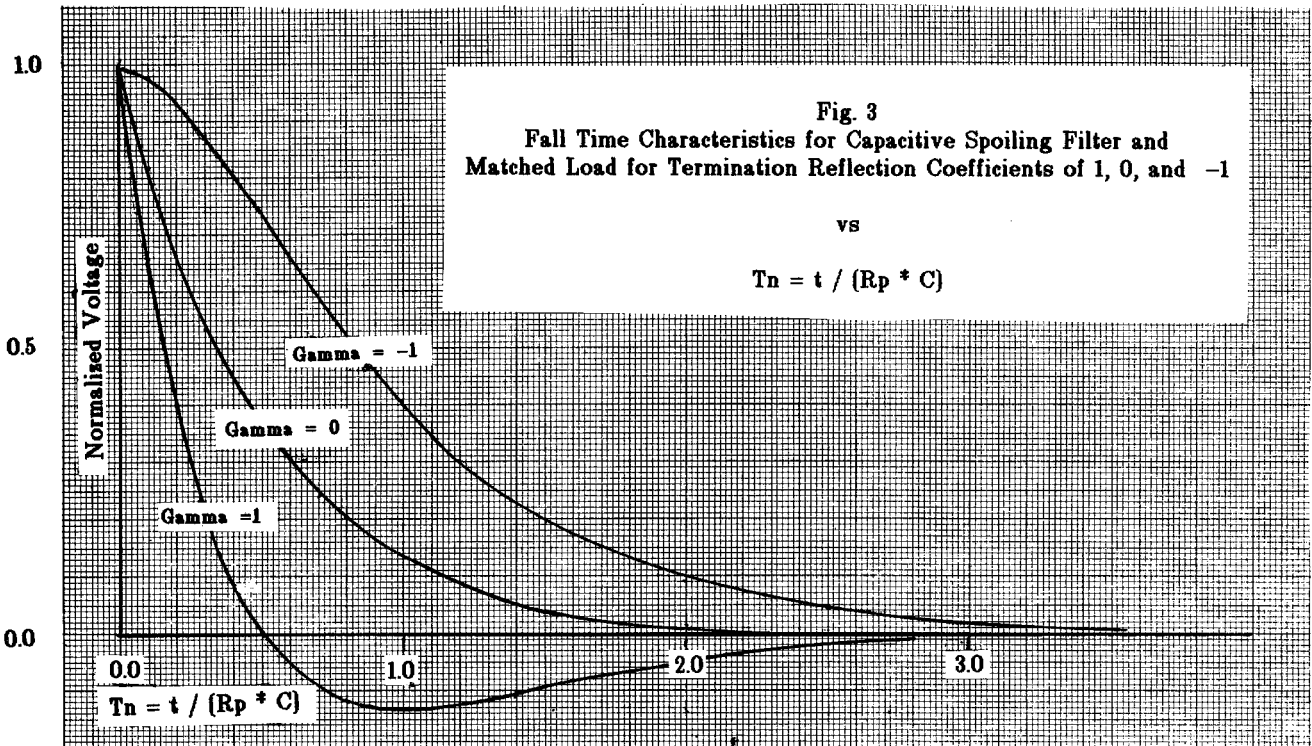
$t$  = time measured from the end of the pulse

Gamma = voltage reflection coefficient

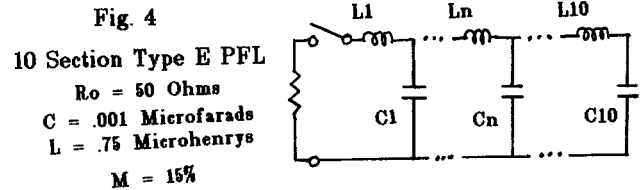
$$\text{Gamma} = (R_t - Z_o) / (R_t + Z_o)$$

Equations (6) and (7) are plotted in Figs. 2 and 3 for matched loads and for Gammas of 1, 0, and -1. The plots are normalized with respect to the natural time constant of the circuit as defined in the figures. The fall time curves are a bit similar except that the influence of Gama is quite different for the two spoiling filter models.

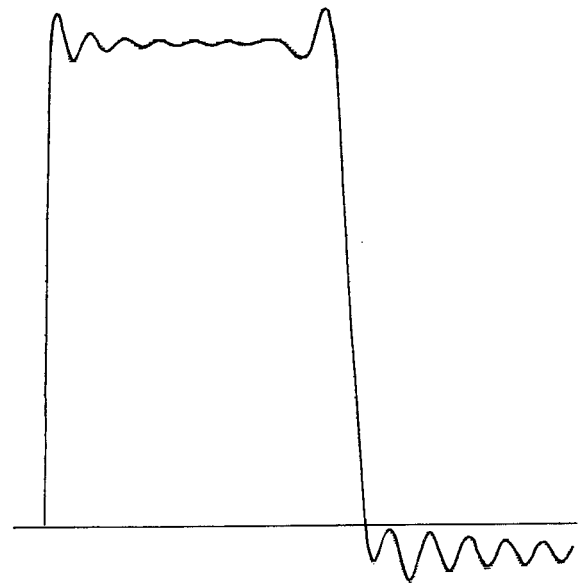




Obviously the minimum fall time will occur when the reflected waveform of equations (2) or (4) arrive at the load with a negative polarity. This occurs when Gamma is -1 for equation (2) and +1 for equation (4). The longest fall times occur when the Gammas are reversed and the fall times are the same when Gamma is 0 in both cases. To implement the desired Gamma it is necessary to use a synchronized switch at the far end of the PFL except for a Gamma of +1, which is an open circuit. In the other cases the switch must close as the reflection from the load end arrives at a time delayed from the main output switch which is equal to one half of the output pulse length. The termination is either a matched load for Gamma of 0 or a short circuit for a Gamma of -1.



For the situation where the PFL is a true coaxial or other type distributed parameter line, the model of the circuits used for the analysis as shown in Fig. 1 are a very good approximation and it is to be expected that the results will be accurately accounted for by the curves of Fig. 2 and Fig. 3. However, if the PFL is a lumped parameter type, such as the Type E line shown in Fig. 4, the analysis is somewhat uncertain. For one thing, the switch at the far end of the line cannot, in real applications, be operated into a short circuit to obtain the Gamma of -1 because it would be a dead short on the final capacitor of the E line. Therefore, one must soften the short circuit with some inductance and resistance to limit the peak current to an acceptable level. Also, the propagation and reflection of the waves in a lumped PFL may not be sufficiently similar to the distributed line case. In order to test the behavior of a lumped PFL under the end of line tailbiter conditions, the E line shown in Fig. 4 was modeled and analyzed using a computer modeling method [1] [2].



**Fig. 5**  
Response of E Type PFL of Fig. 4

The matched output of the basic Type E PFL in Fig. 4 is shown in Fig. 5 and is a well formed rectangular pulse. The circuit was then modified with spoiling filters and inductance and resistance in the far end termination for both types of spoiling filter. The results for the three termination Gammas are shown in Fig. 6 and Fig. 7. As expected, the results are similar to the distributed PFL ideal case but are different. Other tests run, but not shown here, indicated that the difference is more pronounced as the degree of degradation introduced by the spoiling filter approaches the natural rise time of the lumped parameter PFL, as would be logically expected.

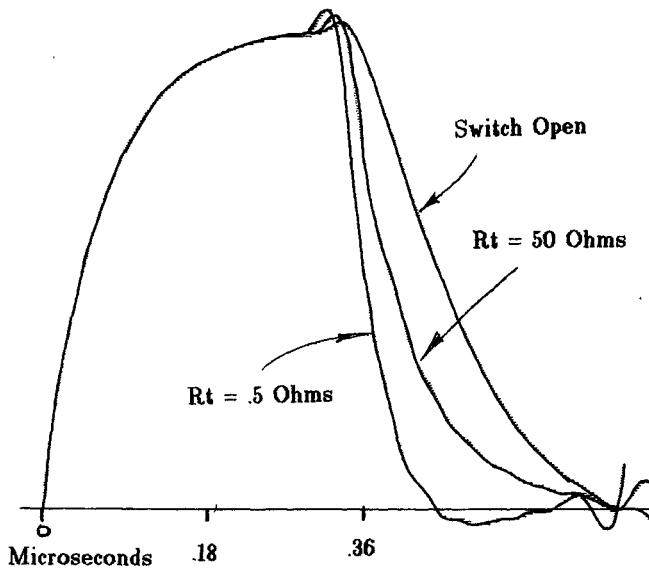


Fig. 6

Response of 10 Section Type E PFL  
With Inductive Spoiling Filter

Switch Closes @ .18 Microseconds

$R_t = .5 \text{ Ohms or } 50 \text{ Ohms}$

$L_t = 75 \text{ nH}$

$L_s = 6.6 \text{ Microhenrys}$

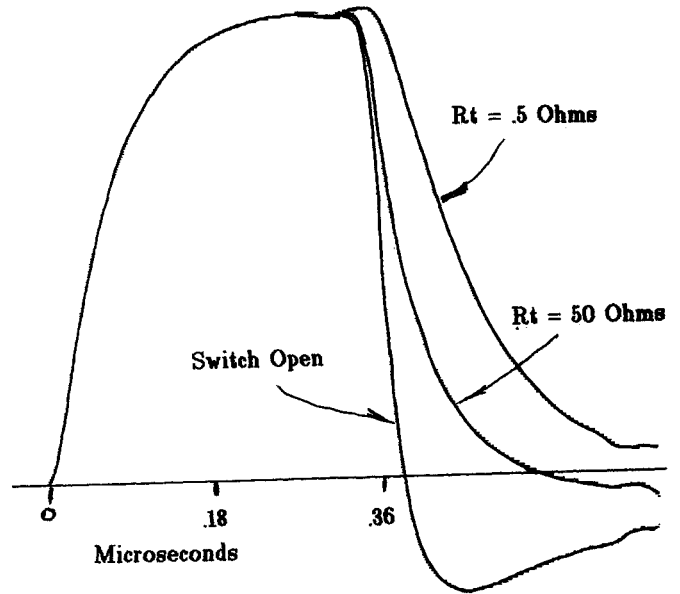
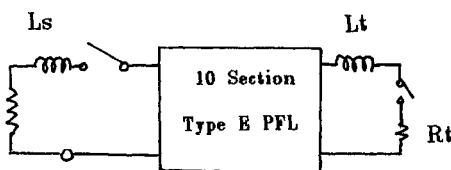


Fig. 7

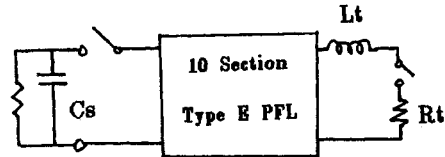
Response of 10 Section Type E PFL  
With Capacitive Spoiling Filter

Switch Closes at .18 Microseconds

$R_t = .5 \text{ Ohms or } 50 \text{ Ohms}$

$L_t = 75 \text{ nH}$

$C_s = 2.5 \text{ nF}$



**Conclusion.** By using a switch and termination impedance at the far end of a PFL, and by synchronizing the switch to close at an electrical delay time equal to the one way time length of the PFL, it has been shown that one may affect the fall time of the load pulse. The degree to which the fall time is affected will depend upon the type of PFL and the equivalent "spoiling" impedance at the load end. The option of locating a tailbiter at the far end of a PFL is convenient for many applications where "real estate" is at a premium.

#### References

- [1] O'Loughlin, James P.; Transient Ciucuit Analysis on Small Computers, 1984 , Sixteenth Power Modulator Symposium, Lib Cong:84 - 81084, pp.216-219.
- [2] O'Loughlin, James P.; Transmission Line Analysis on Personal Computers, 1986 , Seventeenth Power Modulator Symposium, Lib Cong:85 - 82475, pp.166-169.