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LB-930

DESIGN OF VIDEO-AMPLIFIER PEAKING CIRCUITS FOR OPTIMUM TRANSIENT RESPONSE

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Approved

Introduction

This bulletin presents design data for video amplifier peaking circuits which yield maximum gain for a given rise time. Although considerable data are available describing the performance of particular peaking networks, complete data have not been available except for a few specific ratios of input and output capacitance. Information has also been lacking on the effect of variations in component values on the overall transient response.

In this bulletin the transient response and amplitude response of shunt, series, shunt-series, and shunt m-derived peaking networks are given with the circuits adjusted to yield the minimum rise time consistent with a single 3 per cent overshoot. In the case of the series and shunt-series networks where a number of capacitance ratios are possible, five ratios ranging from ¼ to 4 are described in detail. The networks are then compared as to rise time, bandwidth improvement, and sensitivity to variations in circuit parameters.

It is frequently necessary to correct for i-f amplifier phase distortion by the introduction of non-linear phase compensation in the video amplifier. In such cases, the normalized curves given here are useful only as a starting point. However, the curves are directly applicable in video amplifier design where phase compensation for distortion introduced in other parts of the system is not required. Where the input signal has appreciable rise time, the design must be modified since the data presented are based on a unit step or square-wave input.

General Discussion

The transient response of a simple resistance-coupled amplifier is shown in Fig. 1. The rise time corresponds to the time interval between the 10 and 90 per cent response points. The insertion of a peaking network extends the high-frequency response of the amplifier and consequently shortens the rise time to τ_0' as shown by the solid curve which represents a typical four-terminal peaking circuit. The reduced rise time and the improved symmetry are the result of the more linear phase response and increased bandwidth accomplished by peaking. Peaking circuits tend to introduce an overshoot whose amplitude γ, and duration τ_1 may be measured as indicated. A poor choice of circuit constants may impair the phase characteristic to such an extent that smear or ringing may be present. Smear is characterized by an abnormally slow rise of the unit step response as the steady-state level is approached, while ringing denotes an oscillatory approach to the final response.

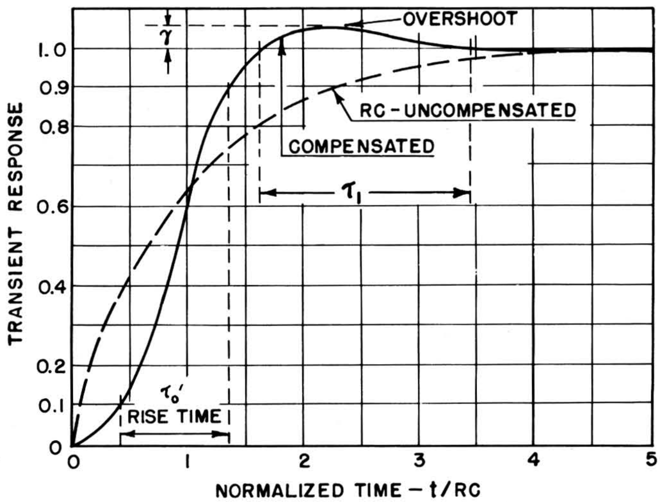

Fig. 1 – Transient response of a typical four-terminal peaking network. The overshoot γ, and overshoot duration τ_1, are measured as shown. When smear exists, these factors are evaluated as shown in Fig. 16 (b).

In order to evaluate the improvement in rise time for a particular peaking network, it is convenient to express the rise time as an improvement over the uncompensated case as follows:

$$\tau_0/\tau_0' = 2.2\,RC/\tau_0'$$

where $\tau_0 = 2.2RC$ is the rise time of the circuit without peaking, and τ_0' is the rise time with the peaking network inserted.

The overshoot duration, τ_1, is normalized with respect to the rise time of the associated unit step response, and takes the form τ_1/τ_0'. The bandwidth improvement is conventionally expressed as the ratio f_0'/f_0 where f_0' is the 3-db bandwidth of the compensated amplifier and $f_0 = 1/2\pi RC$ is the 3-db bandwidth of the circuit without peaking.

The several peaking circuits considered in this bulletin and a summary of the performance of each circuit are given in Table I. For each of the capacitance ratios the following data are tabulated: rise time improvement, 3-db bandwidth improvement, overshoot duration, and the normalized values of the circuit components. These data are supplemented by the actual transient and amplitude response curves in the accompanying figures. The effect of variations in each of the circuit components is described by additional response curves.

To obtain the data, the circuit constants were adjusted to obtain the minimum rise time corresponding to a 3 per cent overshoot. An experimental rather than an analytical approach was used because of the large number of variables involved.

In peaking networks where there are several parameters, variation of each component produces an effect on the transient response which is peculiar to that parameter. Table II shows the characteristic behavior of the shunt-series and shunt m-derived networks. The results indicated assume that coil capacitance is negligible. Capacitance across either the shunt or series coil usually produces an increase in the amount of overshoot.

The data presented in this bulletin describe the unit step response of various video peaking circuits where the criterion is obtaining the shortest rise time consistent with relatively low overshoot. Departures from the design data will be necessary where phase correction is required in the video amplifier for distortion introduced elsewhere in the system. Since the data apply to a single-stage video amplifier, further modification is required where the input to the amplifier has a rise time comparable to the rise time of the peaking circuit itself. In these instances the data given are useful primarily as a starting point.

Shunt Peaking

In shunt peaking the amplitude response is extended by placing an inductance in series with the load resistor so as to resonate with the shunt capacitance. The value of inductance used can be computed from the following relationship:

$$L_2 = mR^2C$$

where R is the load resistance of the stage, C is the total shunt capacitance, and m is a design parameter usually between 0.3 and 0.5. At m = 0.3, the overshoot is 0.5 per cent, increasing to 6.5 per cent at m = 0.5.

The parameter values and performance data for the shunt peaked circuit for various values of m are given in Table I. A 3 per cent overshoot is produced when m = 0.42, the corres-

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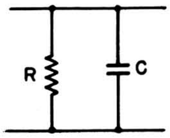
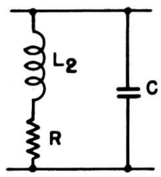
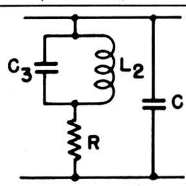
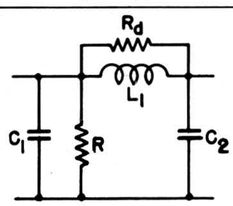
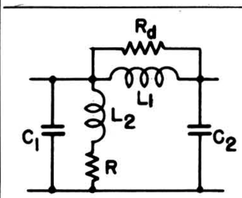
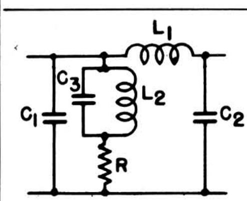
Table I

NORMALIZED CIRCUIT CONSTANTS AND PERFORMANCE DATA FOR VARIOUS PEAKING CIRCUITS

PEAKING CIRCUIT	CAPACITY RATIO C_1/C_2	RISE TIME IMPROVEMENT τ_0/τ_0'	BANDWIDTH IMPROVEMENT f_0'/f_0	OVERSHOOT γ (%)	OVERSHOOT DURATION τ_1/τ_0'	SERIES INDUCTANCE L_1	SHUNT INDUCTANCE L_2	TUNING CAPACITANCE C_3	DAMPING RESISTANCE R_d
 UNCOMPENSATED (RC)		1.00	1.00	0					
 SHUNT PEAKING (FIG. 2)		1.57 1.74 1.82 1.90 2.00	1.50 1.62 1.70 1.76 1.80	0.5 1.25 2.5 4.0 6.5	1.4 2.0 2.6 3.0 3.3		0.30 R^2C 0.35 R^2C 0.40 R^2C 0.45 R^2C 0.50 R^2C		
 TUNED - SHUNT PEAKING (FIG.3)		1.89	1.83	3.0	1.8		0.428R^2C	0.211C	
 SERIES PEAKING $C_1 + C_2 = C$ (FIGS 4 -9)	¼ ½ ½ 1 2 4	1.69 1.24 1.90 1.43 1.51 1.44	1.64 1.21 2.07 1.38 1.37 1.33	3.0 3.0 3.0* 3.0 3.0 3.0	2.0 1.6 0.59 2.0 2.2 2.4	0.571 R^2C 0.789 R^2C 0.544 R^2C 0.952 R^2C 1.38 R^2C 2.51 R^2C			3.11R 3.27R 7.77R 1.88R 2.11R 2.88R
 SHUNT-SERIES PEAKING $C_1 + C_2 = C$ (FIGS 10 - 14)	¼ ½ 1 2 4	1.86 2.21 2.00 2.16 2.36	1.84 2.28 2.00 2.02 2.16	3.0 3.0 3.0 3.0 3.0	2.3 2.2 2.4 2.0 3.7	0.452 R^2C 0.513 R^2C 0.588 R^2C 0.740 R^2C 0.585 R^2C	0.125R^2C 0.138R^2C 0.179R^2C 0.245R^2C 0.430R^2C		— — 2.67R 2.37R 1.78R
 SHUNT M-DERIVED PEAKING $C_1 + C_2 = C$ (FIG. 16)	½	2.47	2.48	0.3**	1.3	0.466 R^2C	0.133R^2C	0.146C	

*ringing (see text) **smear

Table II

Qualitative Effects of Parameter Variation on Transient Response	
Parameter	*Effect on Transient Response*
Series Inductance	Increasing the series inductance increases the overshoot and the rise time.
Shunt Inductance	Increasing the shunt inductance widens the overshoot and decreases the rise time.
Load Resistance	Increasing the load resistance reduces the overshoot and tends to introduce smear. The rise time is increased.
Terminating Capacitance Ratio (C_1/C_2)	Generally produces ringing when variation is large.
Damping Resistance (series coil)	Increase of R_d introduces ringing, especially when $C_1/C_2 > \frac{1}{2}$. Decrease of R_d reduces or eliminates overshoot, but also increases the rise time.
Damping Resistance (shunt coil)	Damping across the shunt coil severely increases the rise time and is preferably omitted.

ponding rise time and bandwidth improvements being 1.85 and 1.72 respectively. The overshoots produced by the shunt peaked circuit are of comparatively long duration. Peaks in the amplitude response become significant for values of $m > 0.5$.

Shunt peaking is relatively tolerant of variations in the single peaking coil employed. The overshoot varies from 1.3 per cent to 4.0 per cent for a ± 10 per cent variation in L_2 about the mean value corresponding to $m = 0.4$. Since $L = mR^2C$, a ± 10 per cent variation in C or a ± 5 per cent variation in the load resistance would affect the response by a similar amount.

Tuned-Shunt Peaking

An improvement over the conventional shunt-peaked circuit can be obtained by tuning the shunt inductance. When $m = 0.4$, the shape of the transient response is similar to that of the shunt network up to the 90 per cent point; beyond this point the slope becomes considerably steeper and the duration of the overshoot is reduced. Investigation of tolerances shows that the network is slightly more critical than the simple shunt configuration. A ± 10 per cent variation in the inductance produces a change in overshoot from 1.5 to 4.7 per cent; the change in rise time is negligible. A 10 per cent decrease in C_3 substantially reduces the overshoot while a 10 per cent increase in C_3 increases the overshoot; both variations occur without appreciably affecting the rise time. The tuned-shunt network may also be adjusted to produce an overshoot less than 3 per cent with a similar improvement in the shape of the transient response, although the rise time is increased.

Four-Terminal Networks

Increased gain for a given rise time (bandwidth) can be obtained by using the four terminal peaking networks shown in Table I. The separation of output and input capacitance results in increased gain, and the use of the filter configuration makes possible an improvement in the phase characteristic so that the unit step response is more symmetrical than fc two-terminal networks.

Series Peaking

The performance obtainable with series peaking, the simplest of the four-terminal networks, is summarized in Table I. The corresponding transient and amplitude response characteristics are shown for five capacitance ratios ranging from $C_1/C_2 = \frac{1}{4}$ to $C_1/C_2 = 4$. The effect of variations in the circuit parameters for each of these cases is shown in the figures.

For the case where $C_1/C_2 = \frac{1}{2}$, which most nearly approaches the filter case, the performance is shown for two criteria of adjustment: (1) In Fig. 5, the circuit constants are adjusted for a single 3 per cent overshoot with no ringing following this overshoot. (2) In Fig. 6, the circuit constants are adjusted for a 3 per cent overshoot followed by ringing as shown. The marked improvement in the rise time ($\tau_o/\tau_o' = 1.90$) where ringing follows the 3 per cent initial overshoot in criterion 2, as against the relatively slow rise time ($\tau_o/\tau_o' = 1.24$) where the circuit is adjusted for no ringing, is apparent. For capacitance ratios other than $C_1/C_2 = \frac{1}{2}$, only the characteristics corresponding to a single 3 per cent overshoot are shown. Where ringing is permissible, a slight alteration in circuit constants will in general result in an improvement in the rise time which, however, will be smaller than the improvement shown for the $C_1/C_2 = \frac{1}{2}$ case.

Shunt-Series Peaking

The performance of the shunt-series peaking network is summarized in Table I and described in detail in Figs. 10-14. Shunt-series (or series-shunt) peaking is more widely used than any other circuit because its parameters, including the series and shunt inductances, as well as the damping across the series coil, can be adjusted to provide a good gain-rise time ratio and a fairly symmetrical transition over a wide input-to-output capacitance ratio.

Reduced rise time can be obtained if ringing is permitted, as against a single overshoot. As in the other circuits, the rise time decreases as the circuit is adjusted to produce increasing overshoot.

Reciprocity

The data summarized for the series peaking and shunt-series peaking networks in Table I show five capacitance ratios. The data for any one of the capacitance ratios may be applied to a given circuit regardless of whether the distribution of capacitances in the video amplifier is such that the input capacitance is greater than or is less than the output capacitance. This point is illustrated in Fig. 15. Thus if it is desired to obtain the performance corresponding to the data given for $C_1/C_2 = 1/N$, the filter will be connected as shown at (a) or (b) depending upon whether C_a is greater or less than C_b. This amounts to interchanging the input and output terminals of the filter and it follows from the reciprocity theorem that the performance will be identical in both cases and will correspond to the data given for $C_1/C_2 = 1/N$.

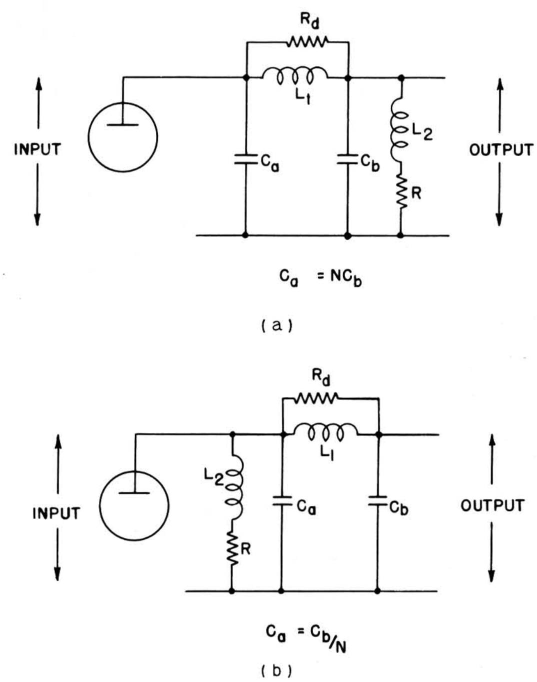


Fig. 15 - Circuits showing the application of the reciprocity theorem to four-terminal peaking networks. For a given capacity ratio N, both networks will give identical performance.

The choice as to whether the $C_1/C_2 = 1/N$ or $C_1/C_2 = N$ configuration is used in a video amplifier depends upon the performance provided by each circuit; this includes not only gain-rise time ratio, but also the shape of the unit step transition, including the width of the overshoot, and the sensitivity of the circuit to variations in component tolerances. These characteristics may be compared by reference to the applicable curves for the circuits involved. An additional factor is the amount of phase and amplitude correction which may be desired to correct for distortions introduced elsewhere in the system, as for example in the i-f amplifier of the television receiver.

Shunt M-Derived Peaking

Where the circuit capacitances are such that $C_1/C_2 = \frac{1}{2}$ (or 2, using reciprocity) improved phase linearity can be obtained by adding a capacitance across the shunt coil of a shunt-series peaking network. When the circuit constants are adjusted for optimum transient response, the rise time is approximately the same as for shunt-series peaking. However, the phase linearity is improved as evidenced by the more symmetrical transition, and the overshoot becomes negligible. This network is sometimes referred to as the Dietzold network. The effect of component tolerances is shown in Fig. 16 (b-f).

Paul F. Hille, Jr.

Jack Avins

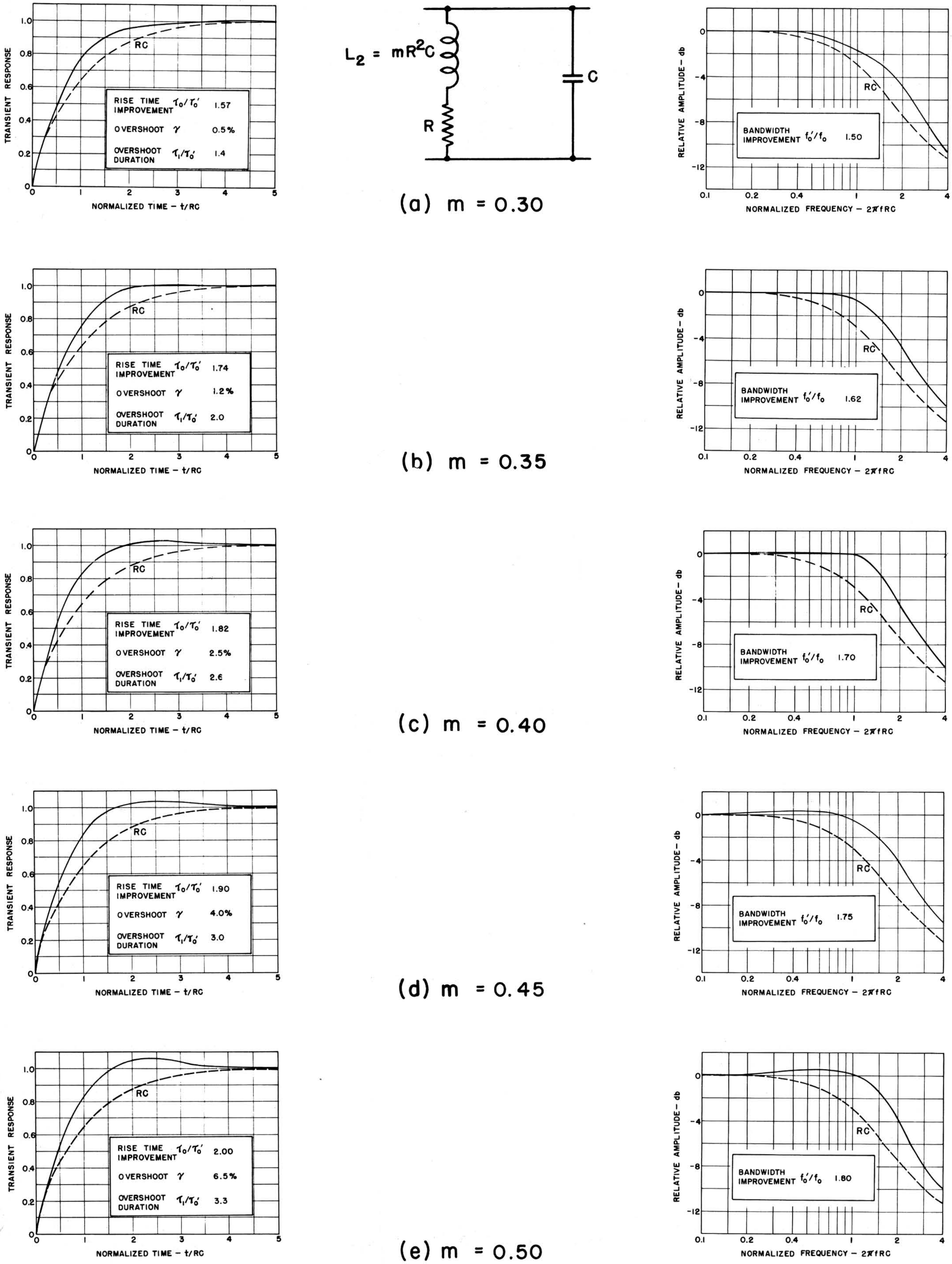


Fig. 2 – Normalized transient and amplitude response of shunt peaking networks for various values of $m = L/R^2C$.

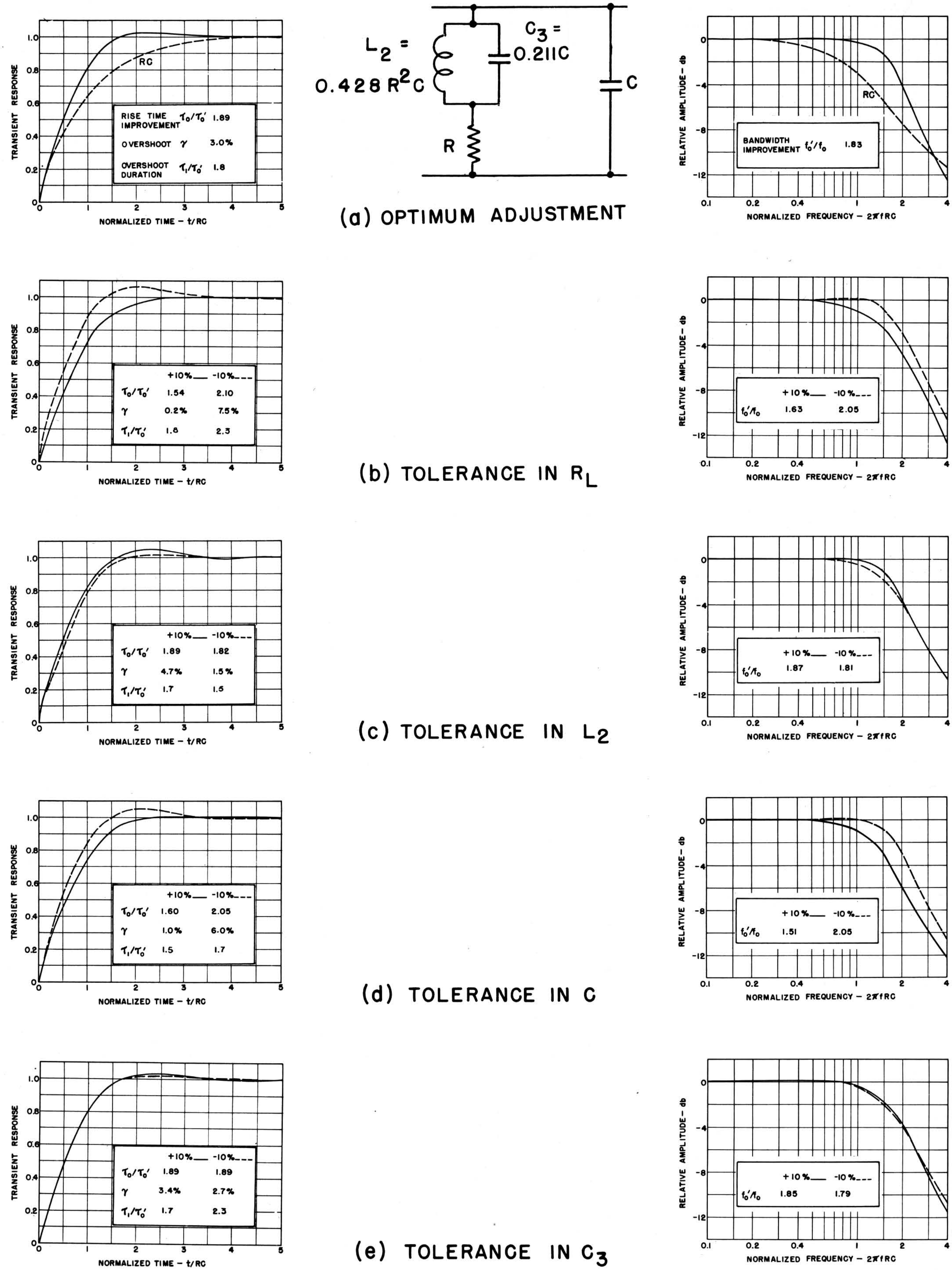


Fig. 3 – Normalized transient and amplitude response of tuned-shunt peaking network adjusted for minimum rise time and a single 3% overshoot. Effect of variation in circuit constants is shown in (b) through (e).

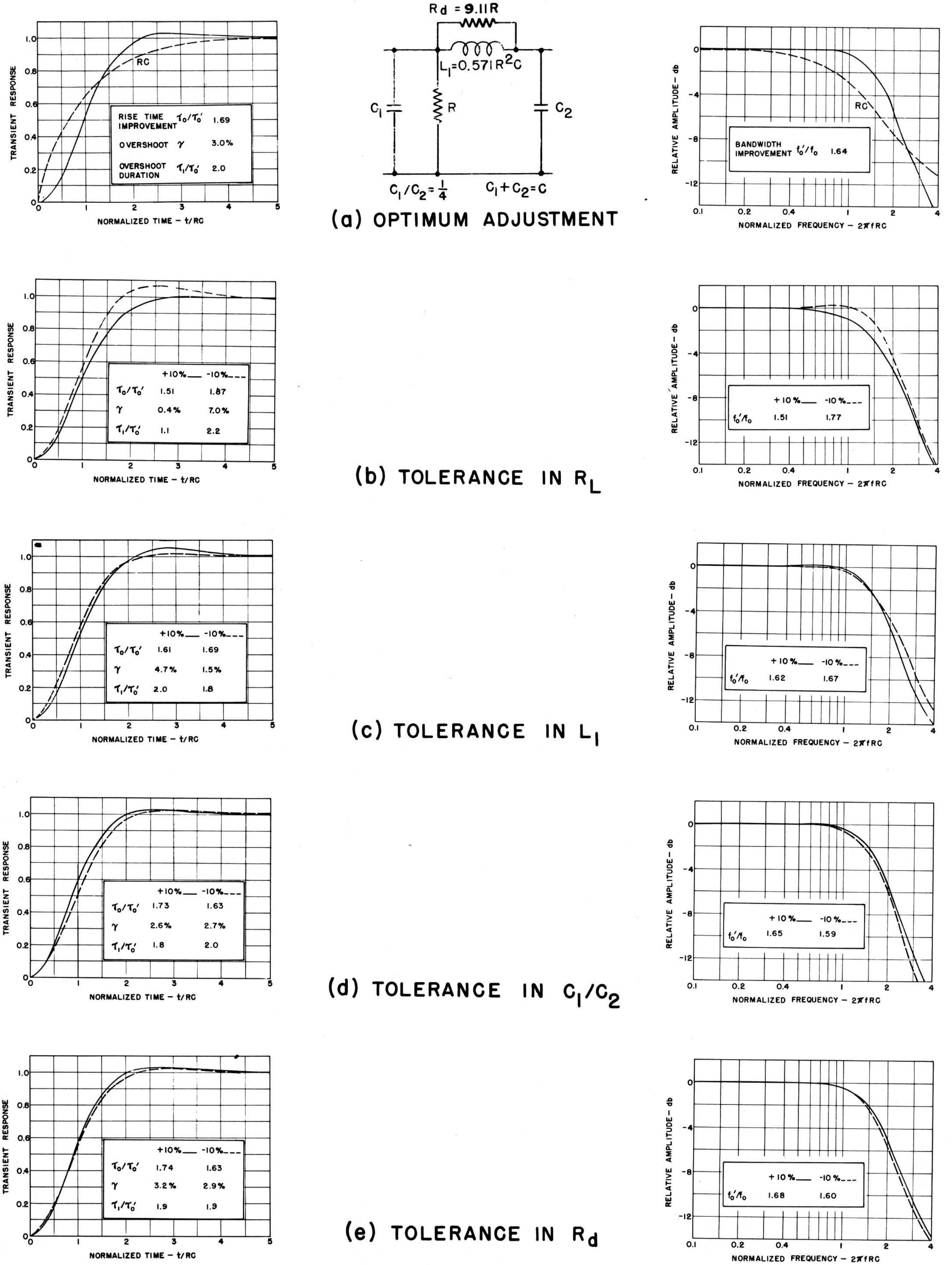


Fig. 4 – Normalized transient and amplitude response of series peaking network, $C_1/C_2 = \frac{1}{4}$, adjusted for minimum rise time and a single 3% overshoot. Effect of variation in circuit constants is shown in (b) through (e).

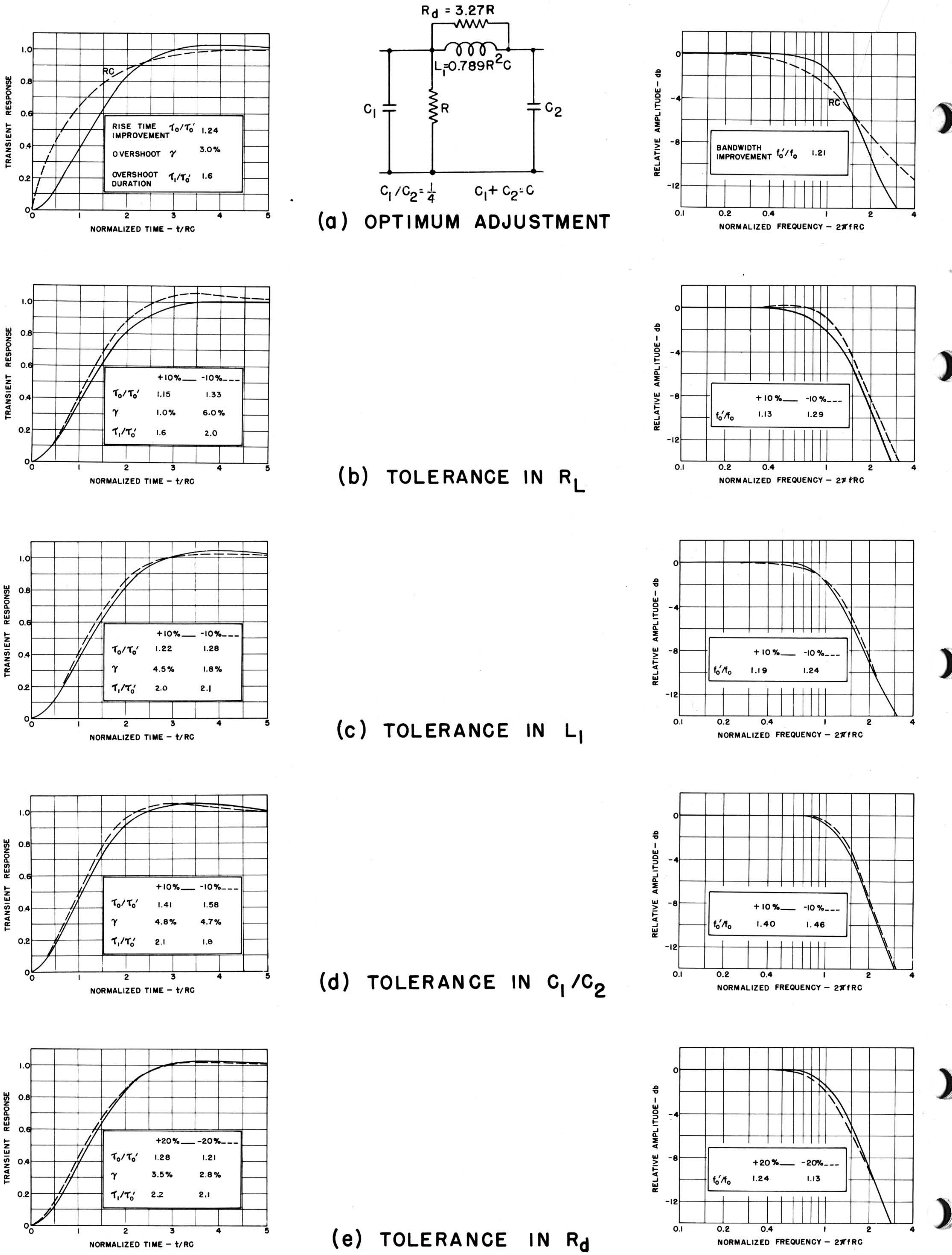


Fig. 5 – Normalized transient and frequency response of series peaking network, $C_1/C_2 = \frac{1}{2}$, adjusted for minimum rise time and a single 3% overshoot. Effect of variation in circuit constants is shown in (b) through (e).

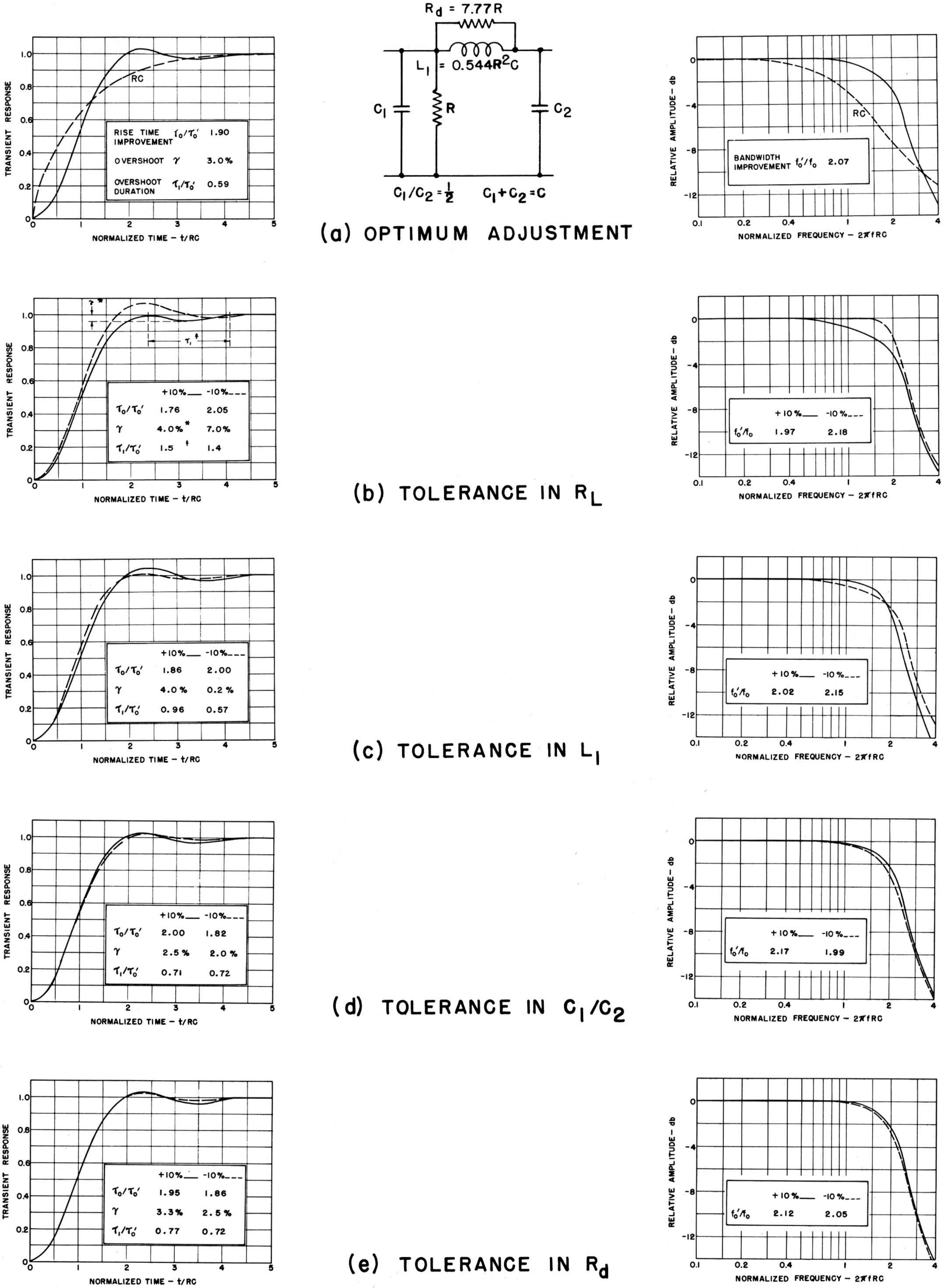


Fig. 6 – Normalized transient and amplitude response of series peaking network, $C_1/C_2 = \frac{1}{2}$, adjusted for minimum rise time and 3% ringing, rather than a single 3% overshoot. Effect of variation in circuit constants is shown in (b) through (e).

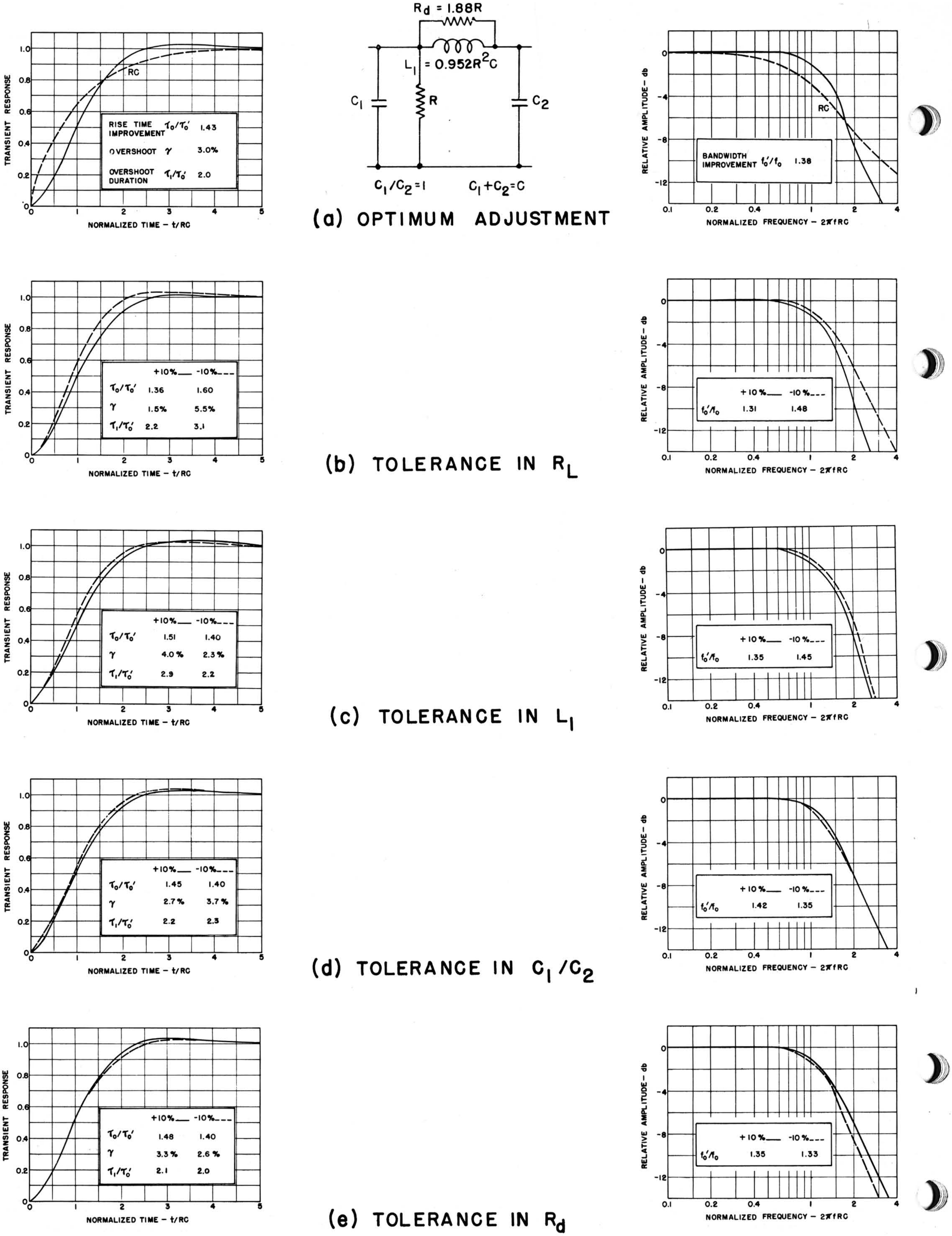


Fig. 7 – Normalized transient and frequency response of series peaking network, $C_1/C_2 = 1$, adjusted for minimum rise time and a single 3% overshoot. Effect of variation in circuit constants is shown in (b) through (e).

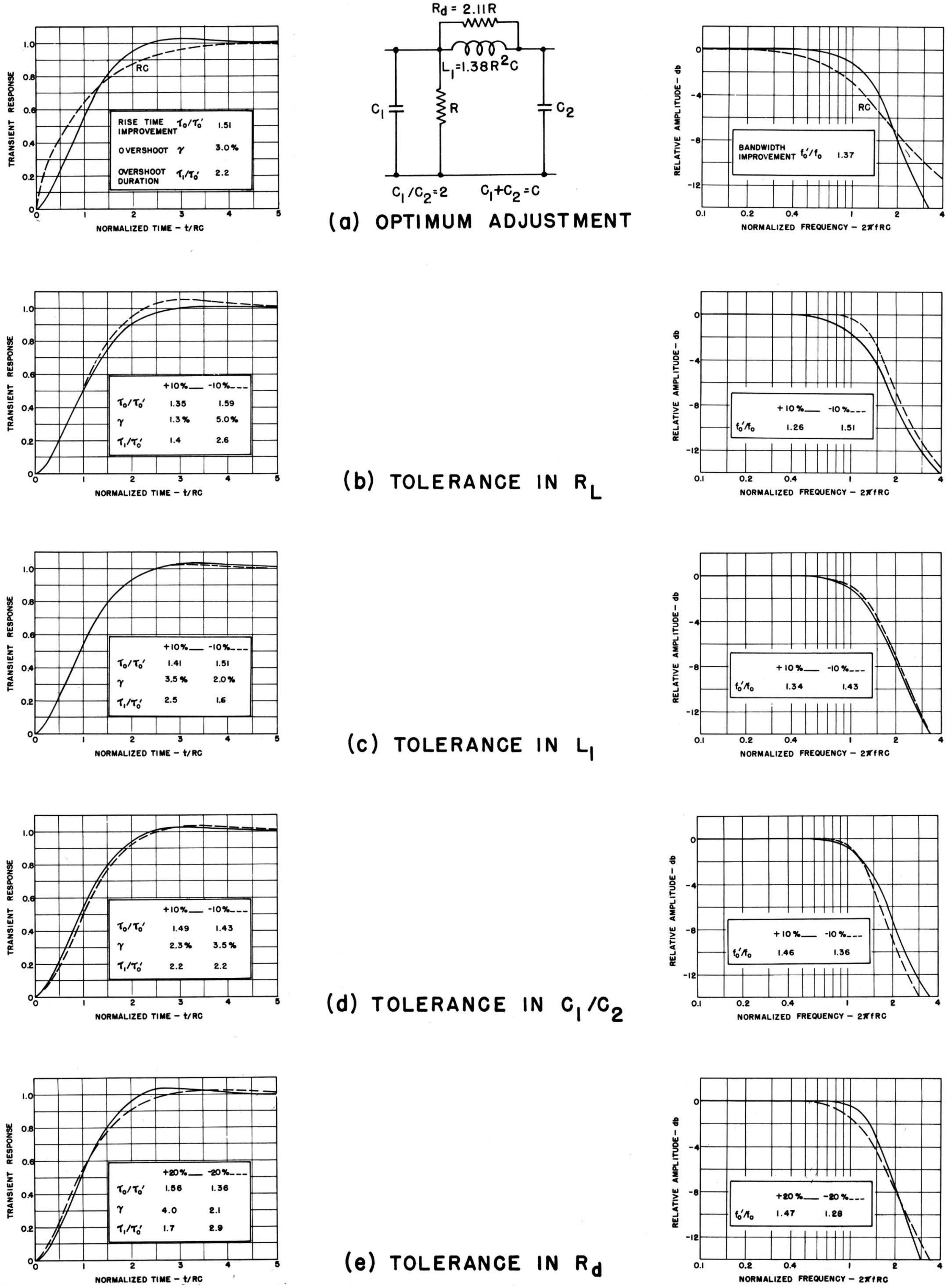


Fig. 8 − Normalized transient and amplitude response of series peaking network, $C_1/C_2 = 2$, adjusted for minimum rise time and a single 3% overshoot. Effect of variation in circuit constants is shown in (b) through (e).

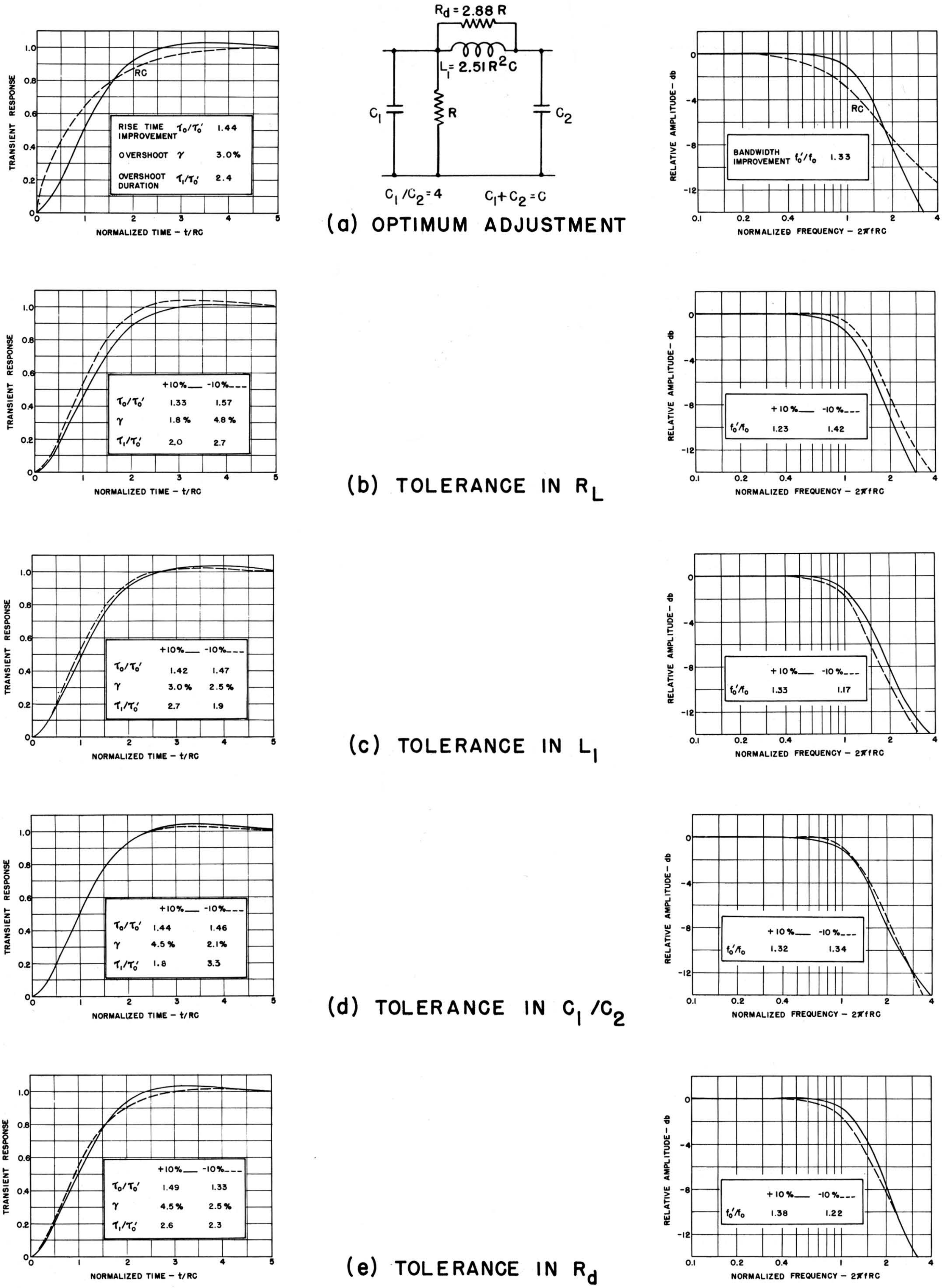


Fig. 9 – Normalized transient and amplitude response of series peaking network, $C_1/C_2 = 4$, adjusted for minimum rise time and a single 3% overshoot. Effect of variation in circuit constants is shown in (b) through (e).

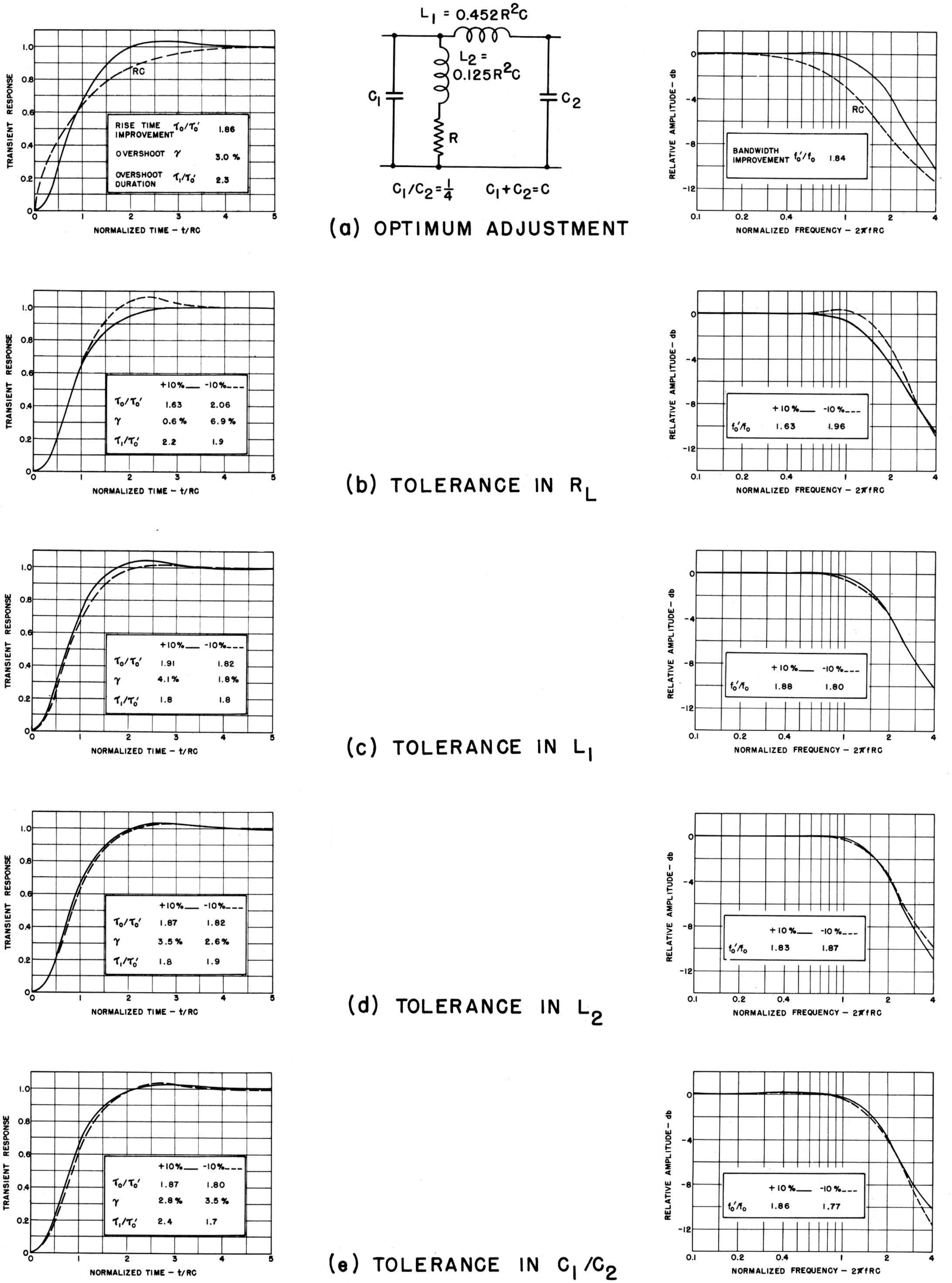


Fig. 10 – Normalized transient and amplitude response of shunt-series peaking network, $C_1/C_2 = \frac{1}{4}$, adjusted for minimum rise time and a single 3% overshoot. Effect of variation in circuit constants is shown in (b) through (e).

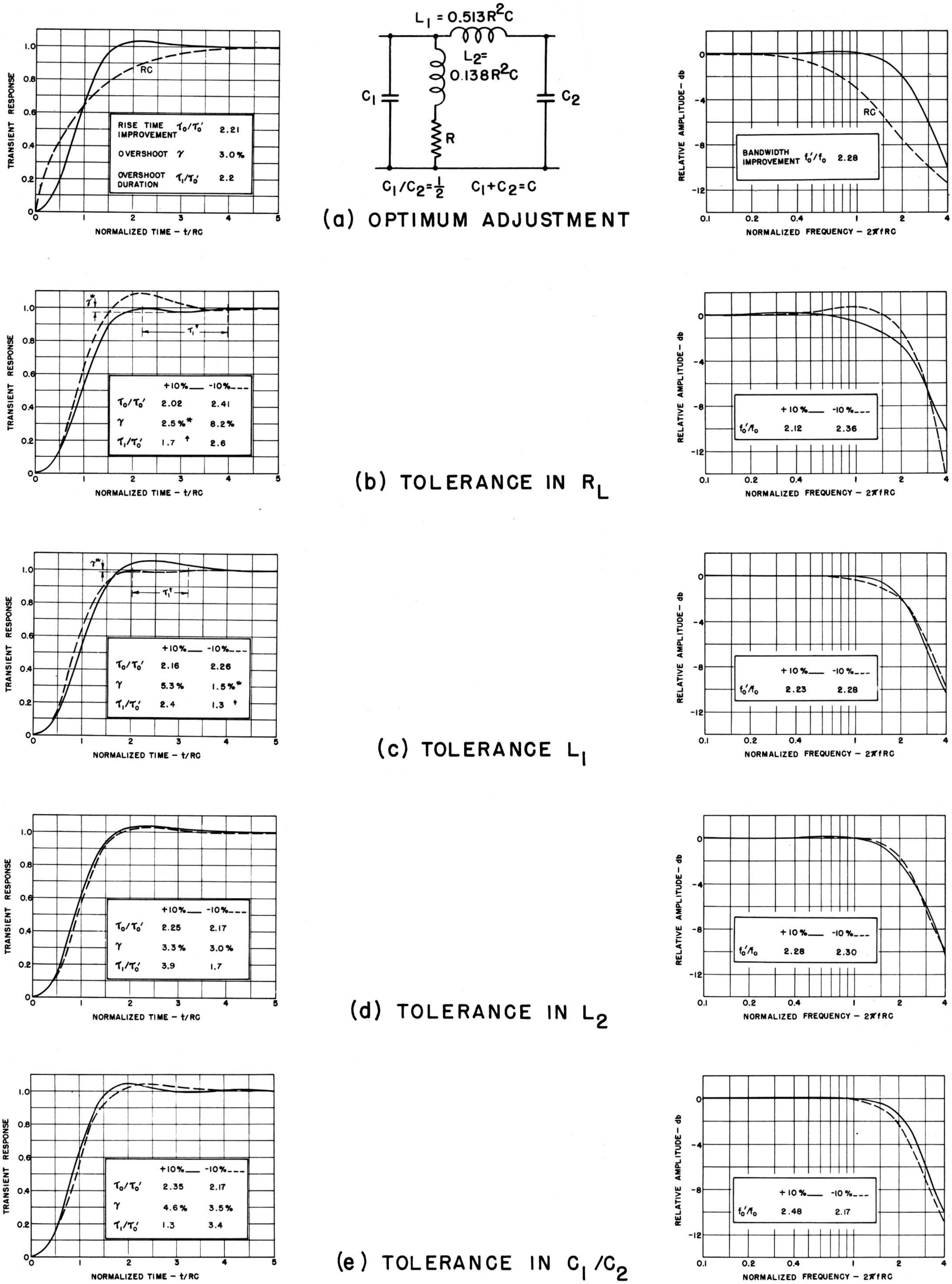


Fig. 11 - Normalized transient and amplitude response of shunt-series peaking network, $C_1/C_2 = \frac{1}{2}$, adjusted for minimum rise time and a single 3% overshoot. Effect of variation in circuit constants is shown in (b) through (e).

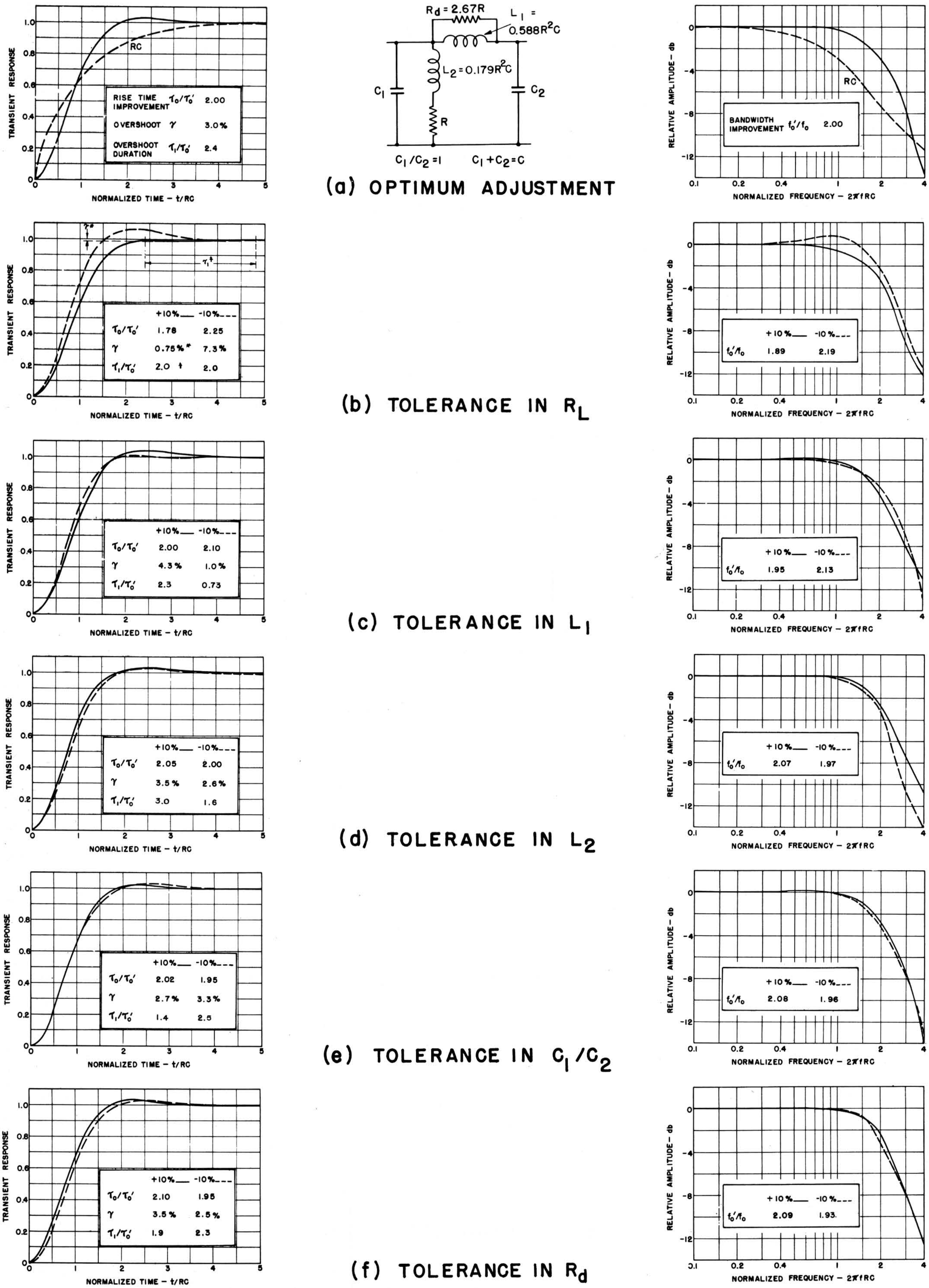


Fig. 12 – Normalized transient and frequency response of shunt-series peaking network, $C_1/C_2 = 1$, adjusted for minimum rise time and a single 3% overshoot. Effect of variation in circuit constants is shown in (b) through (f).

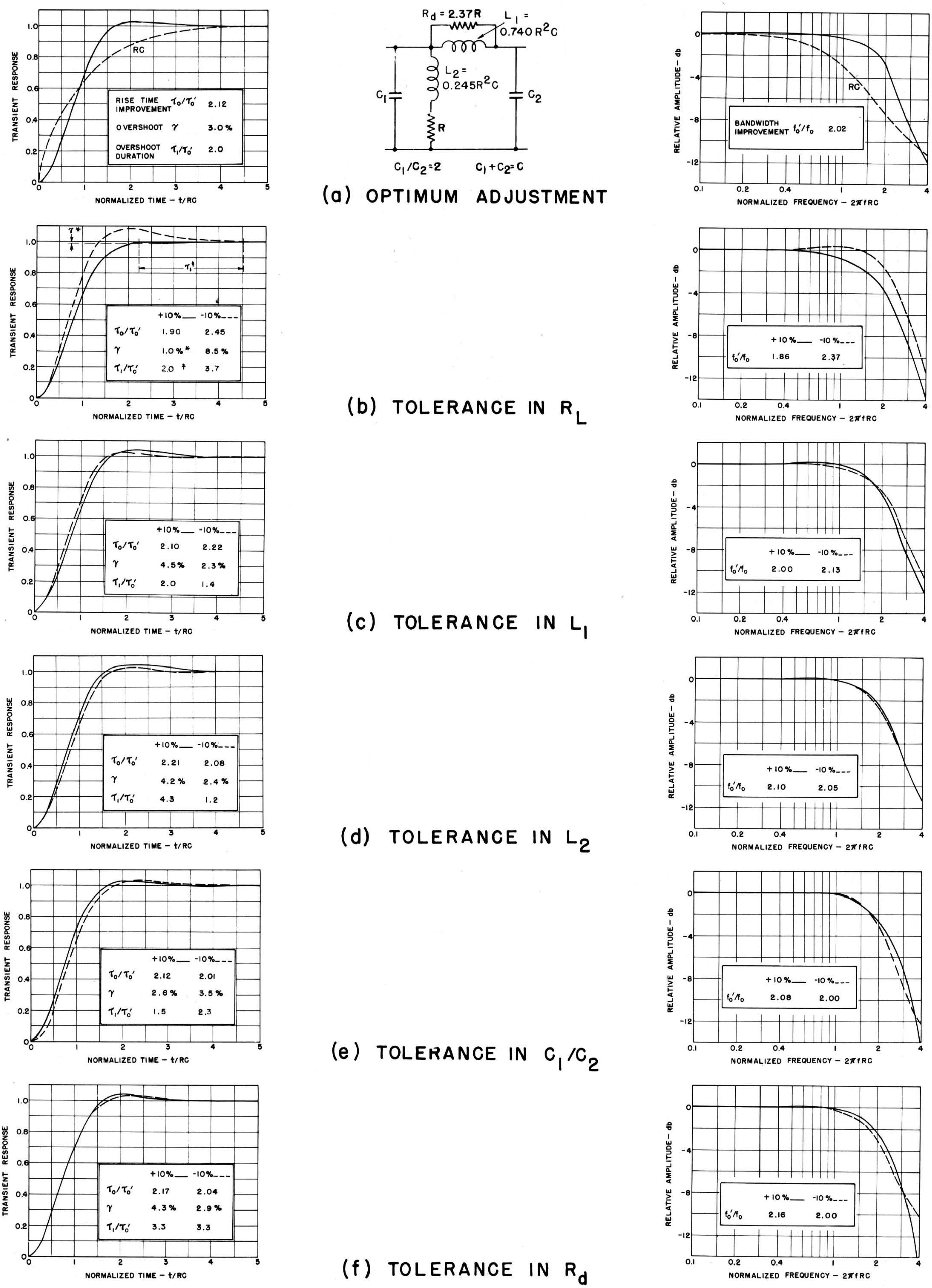


Fig. 13 – Normalized transient and amplitude response of shunt-series peaking network, $C_1/C_2 = 2$, adjusted for minimum rise time and a single 3% overshoot. Effect of variation in circuit constants is shown in (b) through (f).

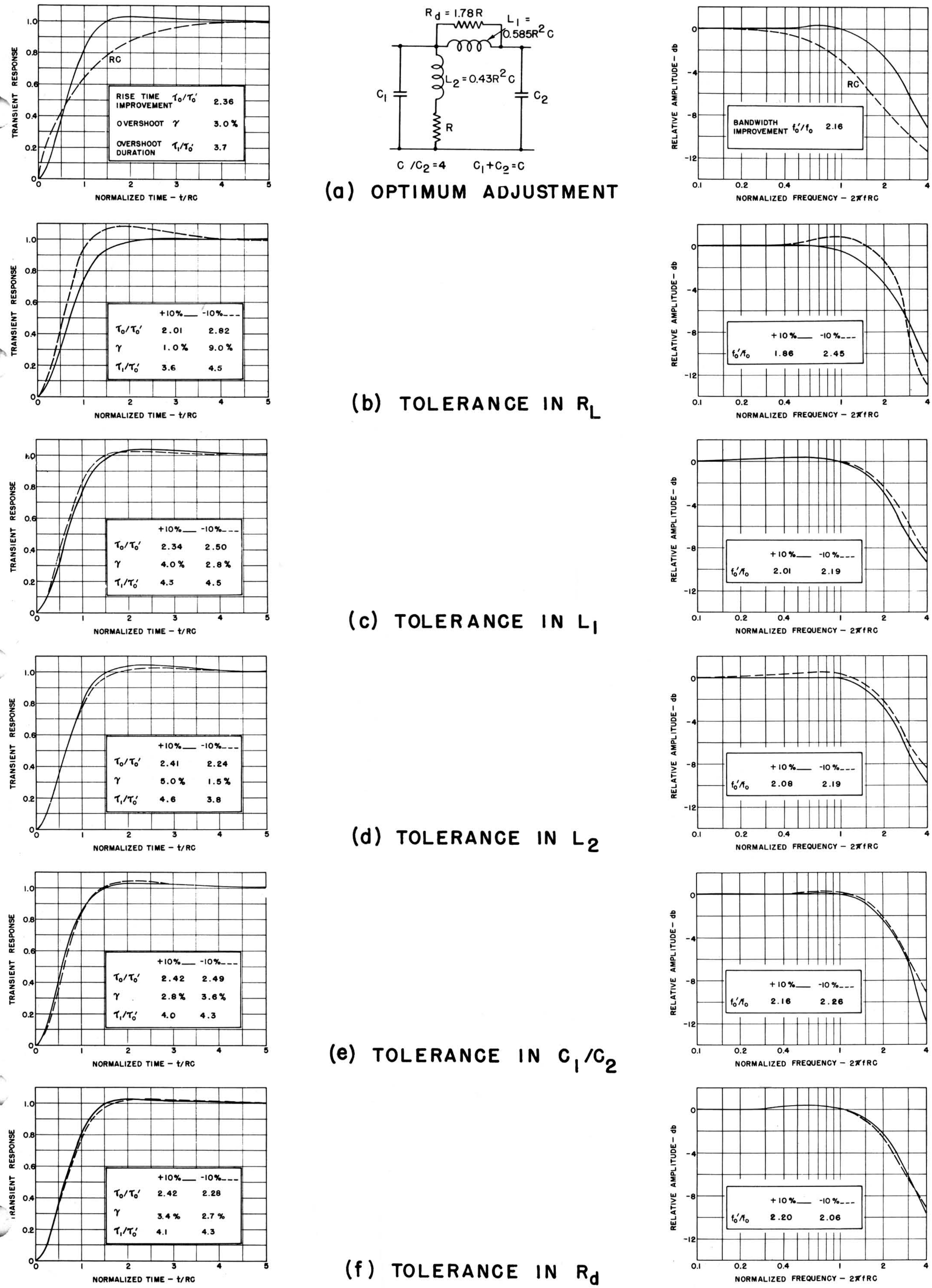


Fig. 14 – Normalized transient and amplitude response of shunt-series peaking circuit, $C_1/C_2 = 4$, adjusted for minimum rise time and a single 3% overshoot. Effect of variation in circuit constants is shown in (b) through (f).

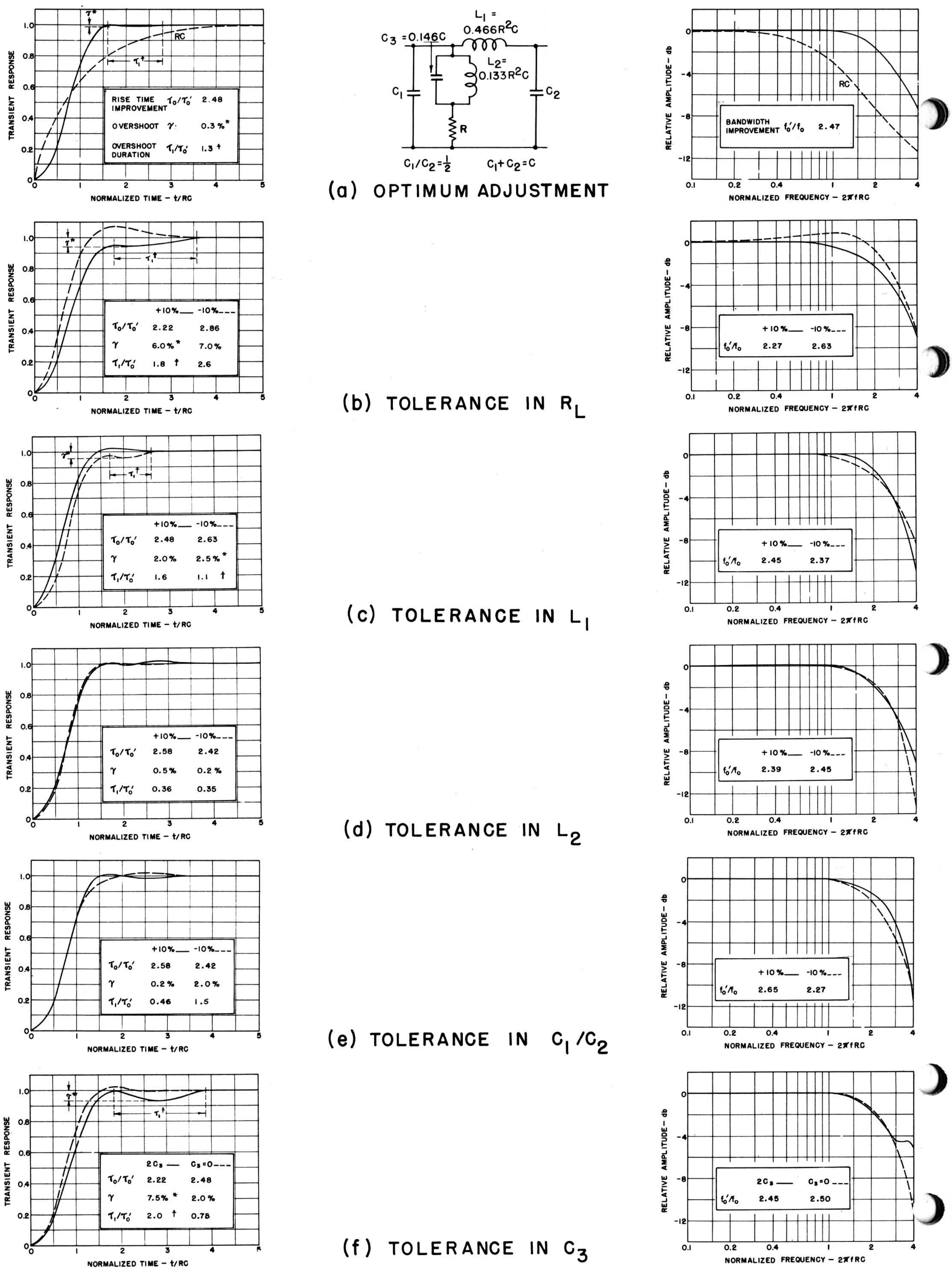


Fig. 16 – Normalized transient and amplitude response of shunt m-derived peaking network (Dietzold's network) adjusted for minimum rise time and a single 3% overshoot. Effect of variation in circuit constants is shown in (b) through (f).