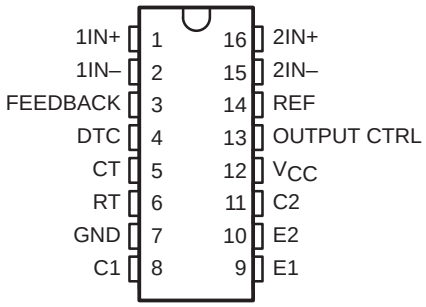
SLVS052D – APRIL 1988 – REVISED AUGUST 2000

- **Complete PWM Power Control Circuitry**
- **Uncommitted Outputs for 200-mA Sink or Source Current**
- **Output Control Selects Single-Ended or Push-Pull Operation**
- **Internal Circuitry Prohibits Double Pulse at Either Output**
- **Variable Dead Time Provides Control Over Total Range**
- **Internal Regulator Provides a Stable 5-V Reference Supply Trimmed to 1%**
- **Circuit Architecture Allows Easy Synchronization**
- **Undervoltage Lockout for Low $V_{CC}$ Conditions**

**D, N, OR PW PACKAGE**
**(TOP VIEW)**




## description

The TL594 incorporates all the functions required in the construction of a pulse-width-modulation (PWM) control circuit on a single chip. Designed primarily for power-supply control, these devices offer the systems engineer the flexibility to tailor the power-supply control circuitry to a specific application.

The TL594 contains two error amplifiers, an on-chip adjustable oscillator, a dead-time control (DTC) comparator, a pulse-steering control flip-flop, a 5-V regulator with a precision of 1%, an undervoltage lockout control circuit, and output control circuitry.

The error amplifiers exhibit a common-mode voltage range from –0.3 V to $V_{CC}$ –2 V. The DTC comparator has a fixed offset that provides approximately 5% dead time. The on-chip oscillator can be bypassed by terminating RT to the reference output and providing a sawtooth input to CT, or it can be used to drive the common circuitry in synchronous multiple-rail power supplies.

The uncommitted output transistors provide either common-emitter or emitter-follower output capability. Each device provides for push-pull or single-ended output operation, with selection by means of the output-control function. The architecture of these devices prohibits the possibility of either output being pulsed twice during push-pull operation. The undervoltage lockout control circuit locks the outputs off until the internal circuitry is operational.

The TL594C is characterized for operation from 0°C to 70°C. The TL594I is characterized for operation from –40°C to 85°C.

**FUNCTION TABLE**

| INPUT OUTPUT CTRL | OUTPUT FUNCTION |
|---|---|
| $V_I$ = –0 | Single-ended or parallel output |
| $V_I = V_{ref}$ | Normal push-pull operation |

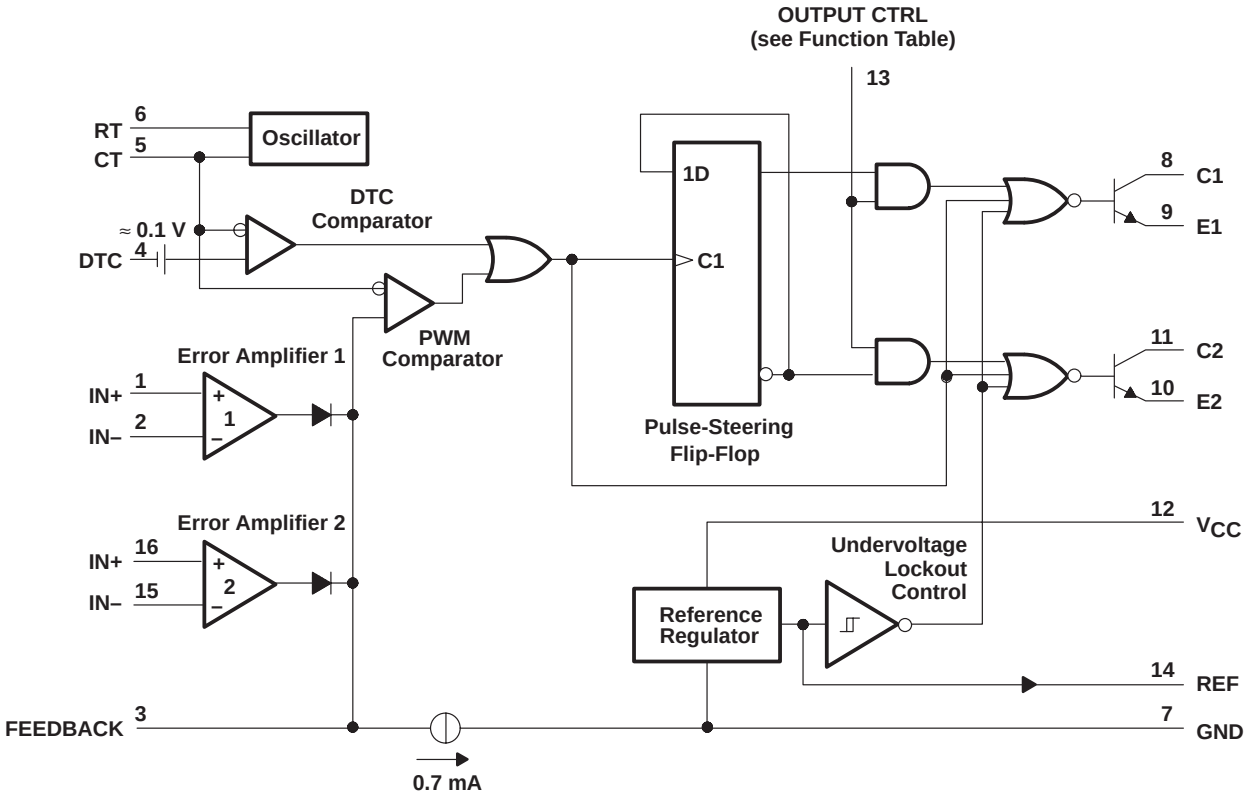
Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

**AVAILABLE OPTIONS**

| $T_A$ | PACKAGED DEVICES | | | CHIP FORM (Y) |
|---|---|---|---|---|
| | SMALL OUTLINE (D) | PLASTIC DIP (N) | PLASTIC THIN SHRINK SMALL OUTLINE (PW) | |
| 0°C to 70°C | TL594CD | TL594CN | TL594CPW | TL594Y |
| –40°C to 85°C | TL594ID | TL594IN | TL594IPW | |

The D and PW packages are also available taped and reeled. Add the suffix R to device type (e.g., TL594CDR). Chip forms are tested at 25°C.

## functional block diagram



## absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage, $V_{CC}$ (see Note 1) . . . . . 41 V
Amplifier input voltage . . . . . $V_{CC}$+0.3 V
Collector output voltage . . . . . 41 V
Collector output current . . . . . 250 mA
Package thermal impedance, $\theta_{JA}$ (see Note 2): D package . . . . . 73°C/W
N package . . . . . 67°C/W
PW package . . . . . 108°C/W
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds . . . . . 260°C
Storage temperature range, $T_{stg}$ . . . . . –65°C to 150°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES: 1. All voltage values, except differential voltages, are with respect to the network ground terminal.
2. The package thermal impedance is calculated in accordance with JESD 51.

## recommended operating conditions

| | | MIN | MAX | UNIT |
|---|---|---|---|---|
| Supply voltage, $V_{CC}$ | | 7 | 40 | V |
| Amplifier input voltage, $V_I$ | | –0.3 | $V_{CC}$–2 | V |
| Collector output voltage, $V_O$ | | | 40 | V |
| Collector output current (each transistor) | | | 200 | mA |
| Current into feedback terminal | | | 0.3 | mA |
| Timing capacitor, $C_T$ | | 0.47 | 10000 | nF |
| Timing resistor, $R_T$ | | 1.8 | 500 | kΩ |
| Oscillator frequency, $f_{osc}$ | | 1 | 300 | kHz |
| Operating free-air temperature, $T_A$ | TL594C | 0 | 70 | °C |
| | TL594I | –40 | 85 | °C |

## electrical characteristics over recommended operating conditions, $V_{CC}$ = 15 V, (unless otherwise noted)

### reference section

| PARAMETER | TEST CONDITIONS† | | TL594C, TL594I | | | UNIT |
|---|---|---|---|---|---|---|
| | | | MIN | TYP‡ | MAX | |
| Output voltage (REF) | $I_O$ = 1 mA, | $T_A$ = 25°C | 4.95 | 5 | 5.05 | V |
| Input regulation | $V_{CC}$ = 7 V to 40 V, | $T_A$ = 25°C | | 2 | 25 | mV |
| Output regulation | $I_O$ = 1 to 10 mA, | $T_A$ = 25°C | | 14 | 35 | mV |
| Output-voltage change with temperature | $\Delta T_A$ = MIN to MAX | | | 2 | 10 | mV/V |
| Short-circuit output current§ | $V_{ref}$ = 0 | | 10 | 35 | 50 | mA |

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
‡ All typical values except for parameter changes with temperature are at $T_A$ = 25°C.
§ Duration of the short circuit should not exceed one second.

### amplifier section (see Figure 1)

| PARAMETER | TEST CONDITIONS | | | TL594C, TL594I | | | UNIT |
|---|---|---|---|---|---|---|---|
| | | | | MIN | TYP‡ | MAX | |
| Input offset voltage, error amplifier | FEEDBACK = 2.5 V | | | | 2 | 10 | mV |
| Input offset current | FEEDBACK = 2.5 V | | | | 25 | 250 | nA |
| Input bias current | FEEDBACK = 2.5 V | | | | 0.2 | 1 | μA |
| Common-mode input voltage range, error amplifier | $V_{CC}$ = 7 V to 40 V | | | 0.3 to $V_{CC}$–2 | | | V |
| Open-loop voltage amplification, error amplifier | $\Delta V_O$ = 3 V, | $R_L$ = 2 kΩ, | $V_O$ = 0.5 V to 3.5 V | 70 | 95 | | dB |
| Unity-gain bandwidth | $V_O$ = 0.5 V to 3.5 V, | $R_L$ = 2 kΩ | | | 800 | | kHz |
| Common-mode rejection ratio, error amplifier | $V_{CC}$ = 40 V, | $T_A$ = 25°C | | 65 | 80 | | dB |
| Output sink current, FEEDBACK | $V_{ID}$ = –15 mV to –5 V, | FEEDBACK = 0.5 V | | 0.3 | 0.7 | | mA |
| Output source current, FEEDBACK | $V_{ID}$ = 15 mV to 5 V, | FEEDBACK = 3.5 V | | –2 | | | mA |

‡ All typical values except for parameter changes with temperature are at $T_A$ = 25°C.

### oscillator section, $C_T$ = 0.01 μF, $R_T$ = 12 kΩ (see Figure 2)

| PARAMETER | TEST CONDITIONS† | TL594C, TL594I | | | UNIT |
|---|---|---|---|---|---|
| | | MIN | TYP‡ | MAX | |
| Frequency | | | 10 | | kHz |
| Standard deviation of frequency¶ | All values of $V_{CC}$, $C_T$, $R_T$, and $T_A$ constant | | 100 | | Hz/kHz |
| Frequency change with voltage | $V_{CC}$ = 7 V to 40 V, $T_A$ = 25°C | | 1 | | Hz/kHz |
| Frequency change with temperature# | $\Delta T_A$ = MIN to MAX | | | 50 | Hz/kHz |

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
‡ All typical values except for parameter changes with temperature are at $T_A$ = 25°C.
¶ Standard deviation is a measure of the statistical distribution about the mean as derived from the formula:

$$\sigma = \sqrt{\frac{\sum_{n=1}^{N} (x_n - \overline{X})^2}{N - 1}}$$

# Temperature coefficient of timing capacitor and timing resistor not taken into account.

## electrical characteristics over recommended operating free-air temperature range, $V_{CC}$ = 15 V, (unless otherwise noted)

### dead-time control section (see Figure 2)

| PARAMETER | TEST CONDITIONS | TL594C, TL594I | | | UNIT |
|---|---|---|---|---|---|
| | | MIN | TYP† | MAX | |
| Input bias current | $V_I$ = 0 to 5.25 V | | –2 | –10 | μA |
| Maximum duty cycle, each output | DTC = 0 V | 0.45 | | | |
| Input threshold voltage | Zero duty cycle | | 3 | 3.3 | V |
| | Maximum duty cycle | 0 | | | |

† All typical values except for parameter changes with temperature are at $T_A$ = 25°C.

### output section

| PARAMETER | | TEST CONDITIONS | TL594C, TL594I | | | UNIT |
|---|---|---|---|---|---|---|
| | | | MIN | TYP† | MAX | |
| Collector off-state current | | $V_C$ = 40 V, $V_E$ = 0 V, $V_{CC}$ = 40 V | | 2 | 100 | μA |
| | | DTC and OUTPUT CTRL = 0 V, $V_C$ = 15 V, $V_E$ = 0 V, $V_{CC}$ = 1 to 3 V | | 4 | 200 | |
| Emitter off-state current | | $V_{CC}$ = $V_C$ = 40 V, $V_E$ = 0 | | | –100 | μA |
| Collector-emitter saturation voltage | Common emitter | $V_E$ = 0, $I_C$ = 200 mA | | 1.1 | 1.3 | V |
| | Emitter follower | $V_C$ = 15 V, $I_E$ = –200 mA | | 1.5 | 2.5 | |
| Output control input current | | $V_I$ = $V_{ref}$ | | | 3.5 | mA |

† All typical values except for parameter changes with temperature are at $T_A$ = 25°C.

### pwm comparator section (see Figure 2)

| PARAMETER | TEST CONDITIONS | TL594C, TL594I | | | UNIT |
|---|---|---|---|---|---|
| | | MIN | TYP† | MAX | |
| Input threshold voltage, FEEDBACK | Zero duty cycle | | 4 | 4.5 | V |
| Input sink current, FEEDBACK | FEEDBACK = 0.5 V | 0.3 | 0.7 | | mA |

† All typical values except for parameter changes with temperature are at $T_A$ = 25°C.

### undervoltage lockout section (see Figure 2)

| PARAMETER | TEST CONDITIONS‡ | TL594C, TL594I | | UNIT |
|---|---|---|---|---|
| | | MIN | MAX | |
| Threshold voltage | $T_A$ = 25°C | | 6 | V |
| | $\Delta T_A$ = MIN to MAX | 3.5 | 6.9 | |
| Hysteresis§ | | 100 | | mV |

‡ For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
§ Hysteresis is the difference between the positive-going input threshold voltage and the negative-going input threshold voltage.

| PARAMETER | TEST CONDITIONS | | TL594C, TL594I | | | UNIT |
|---|---|---|---|---|---|---|
| | | | MIN | TYP† | MAX | |
| Standby supply current | RT at $V_{ref}$, All other inputs and outputs open | $V_{CC}$ = 15 V | | 9 | 15 | mA |
| | | $V_{CC}$ = 40 V | | 11 | 18 | |
| Average supply current | DTC = 2 V, | See Figure 2 | | 12.4 | | mA |

† All typical values except for parameter changes with temperature are at $T_A$ = 25°C.

## electrical characteristics over recommended operating free-air temperature range, $V_{CC}$ = 15 V, (unless otherwise noted) (continued)

### switching characteristics, $T_A$ = 25°C

| PARAMETER | TEST CONDITIONS | TL594C, TL594I | | | UNIT |
|---|---|---|---|---|---|
| | | MIN | TYP† | MAX | |
| Output-voltage rise time | Common-emitter configuration (see Figure 3 | | 100 | 200 | ns |
| Output-voltage fall time | | | 30 | 100 | ns |
| Output-voltage rise time | Emitter-follower configuration (see Figure 4) | | 200 | 400 | ns |
| Output-voltage fall time | | | 45 | 100 | ns |

† All typical values except for parameter changes with temperature are at $T_A$ = 25°C.

## electrical characteristics over recommended operating conditions, $V_{CC}$ = 15 V, $T_A$ = 25°C (unless otherwise noted)

### reference section

| PARAMETER | TEST CONDITIONS | TL594Y | | | UNIT |
|---|---|---|---|---|---|
| | | MIN | TYP | MAX | |
| Output voltage (REF) | $I_O$ = 1 mA | | 5 | | V |
| Input regulation | $V_{CC}$ = 7 V to 40 V | | 2 | | mV |
| Output regulation | $I_O$ = 1 to 10 mA | | 14 | | mV |
| Short-circuit output current‡ | $V_{ref}$ = 0 | | 35 | | mA |

‡ Duration of the short circuit should not exceed one second.

### oscillator section, $C_T$ = 0.01 μF, $R_T$ = 12 kΩ (see Figure 2)

| PARAMETER | TEST CONDITIONS | TL594Y | | | UNIT |
|---|---|---|---|---|---|
| | | MIN | TYP | MAX | |
| Frequency | | | 10 | | kHz |
| Standard deviation of frequency§ | All values of $V_{CC}$, $C_T$, $R_T$, and $T_A$ constant | | 100 | | Hz/kHz |
| Frequency change with voltage | $V_{CC}$ = 7 V to 40 V | | 1 | | Hz/kHz |

§ Standard deviation is a measure of the statistical distribution about the mean as derived from the formula:

$$\sigma = \sqrt{\frac{\sum_{n=1}^{N} (x_n - \overline{X})^2}{N - 1}}$$

### amplifier section (see Figure 1)

| PARAMETER | TEST CONDITIONS | TL594Y | | | UNIT |
|---|---|---|---|---|---|
| | | MIN | TYP | MAX | |
| Input offset voltage, error amplifier | FEEDBACK = 2.5 V | | 2 | | mV |
| Input offset current | FEEDBACK = 2.5 V | | 25 | | nA |
| Input bias current | FEEDBACK = 2.5 V | | 0.2 | | μA |
| Open-loop voltage amplification, error amplifier | $\Delta V_O$ = 3 V, $R_L$ = 2 kΩ, $V_O$ = 0.5 V to 3.5 V | | 95 | | dB |
| Unity-gain bandwidth | $V_O$ = 0.5 V to 3.5 V, $R_L$ = 2 kΩ | | 800 | | kHz |
| Common-mode rejection ratio, error amplifier | $V_{CC}$ = 40 V, $T_A$ = 25°C | | 80 | | dB |
| Output sink current, FEEDBACK | $V_{ID}$ = –15 mV to –5 V, FEEDBACK = 0.5 V | | 0.7 | | mA |

## electrical characteristics over recommended operating free-air temperature range, $V_{CC}$ = 15 V, $T_A$ = 25°C (unless otherwise noted)

### dead-time control section (see Figure 2)

| PARAMETER | TEST CONDITIONS | TL594Y | | | UNIT |
|---|---|---|---|---|---|
| | | MIN | TYP | MAX | |
| Input bias current | $V_I$ = 0 to 5.25 V | | –2 | | μA |
| Input threshold voltage | Zero duty cycle | | 3 | | V |

### output section

| PARAMETER | | TEST CONDITIONS | TL594Y | | | UNIT |
|---|---|---|---|---|---|---|
| | | | MIN | TYP | MAX | |
| Collector off-state current | | $V_C$ = 40 V, $V_E$ = 0 V, $V_{CC}$ = 40 V | | 2 | | μA |
| | | DTC and OUTPUT CTRL = 0 V, $V_C$ = 15 V, $V_E$ = 0 V, $V_{CC}$ = 1 to 3 V | | 4 | | |
| Emitter off-state current | | $V_{CC}$ = $V_C$ = 40 V, $V_E$ = 0 | | | | μA |
| Collector-emitter saturation voltage | Common emitter | $V_E$ = 0, $I_C$ = 200 mA | | 1.1 | | V |
| | Emitter follower | $V_C$ = 15 V, $I_E$ = –200 mA | | 1.5 | | |

### pwm comparator section (see Figure 2)

| PARAMETER | TEST CONDITIONS | TL594Y | | | UNIT |
|---|---|---|---|---|---|
| | | MIN | TYP | MAX | |
| Input threshold voltage, FEEDBACK | Zero duty cycle | | 4 | | V |
| Input sink current, FEEDBACK | FEEDBACK = 0.5 V | | 0.7 | | mA |

### total device (see Figure 2)

| PARAMETER | TEST CONDITIONS | TL594Y | | | UNIT |
|---|---|---|---|---|---|
| | | MIN | TYP | MAX | |
| Standby supply current | All other inputs and outputs open, $R_T$ at $V_{ref}$ | | 9 | | mA |
| Average supply current | DTC = 2 V, See Figure 2 | | 12.4 | | mA |

## switching characteristics, $T_A$ = 25°C

| PARAMETER | TEST CONDITIONS | TL594Y | | | UNIT |
|---|---|---|---|---|---|
| | | MIN | TYP | MAX | |
| Output-voltage rise time | Common-emitter configuration (see Figure 3) | | 100 | | ns |
| Output-voltage fall time | | | 30 | | ns |
| Output-voltage rise time | Emitter-follower configuration (see Figure 4) | | 200 | | ns |
| Output-voltage fall time | | | 45 | | ns |

## PARAMETER MEASUREMENT INFORMATION

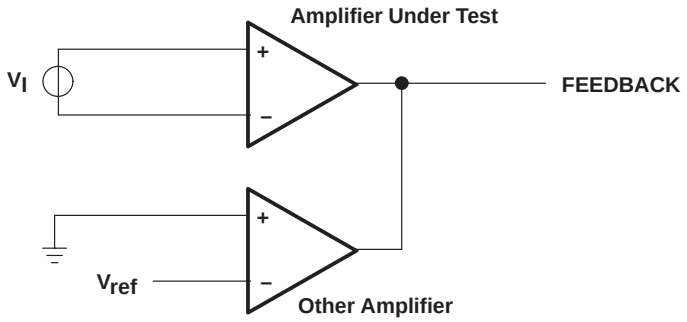



**Figure 1. Amplifier-Characteristics Test Circuit**

## PARAMETER MEASUREMENT INFORMATION

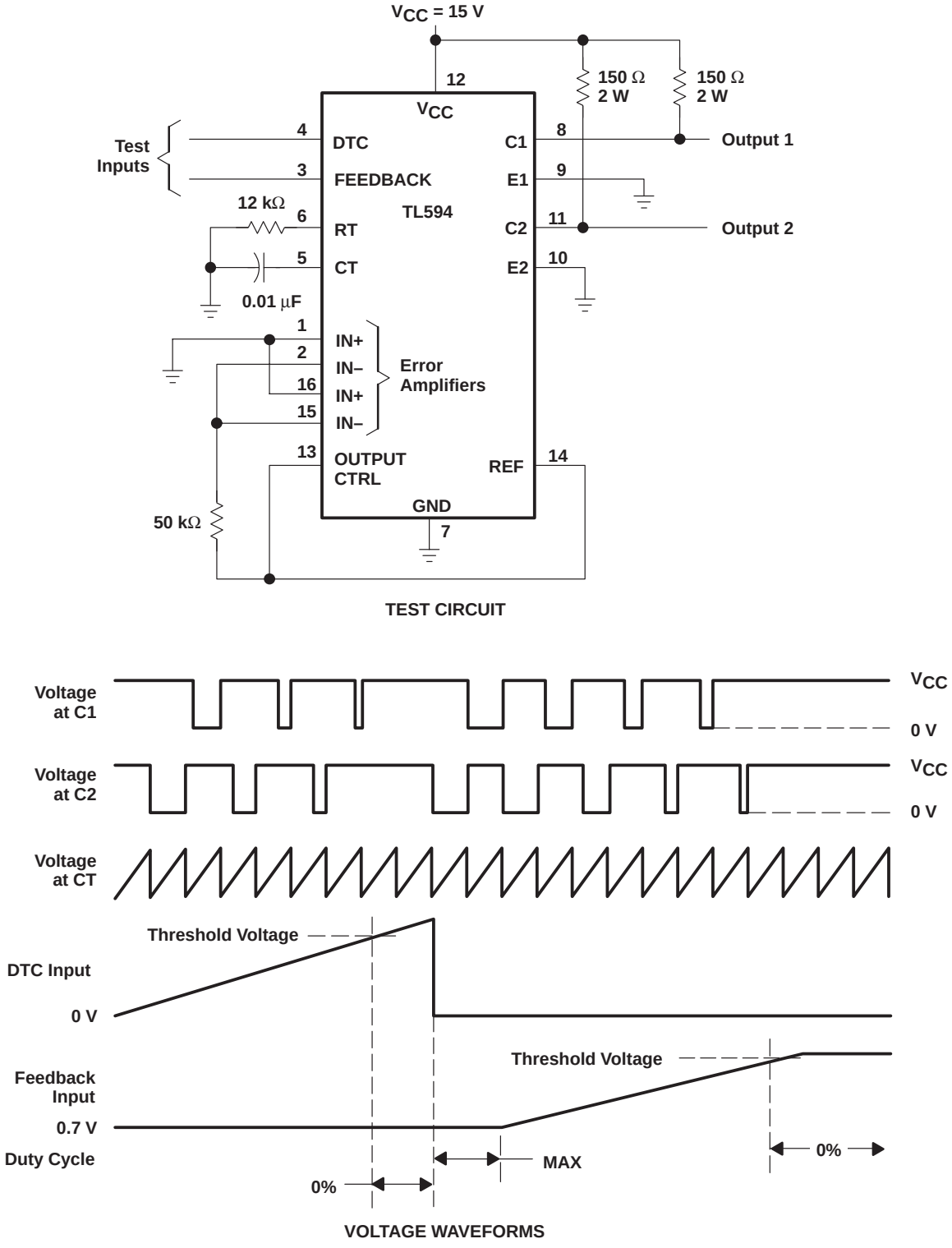
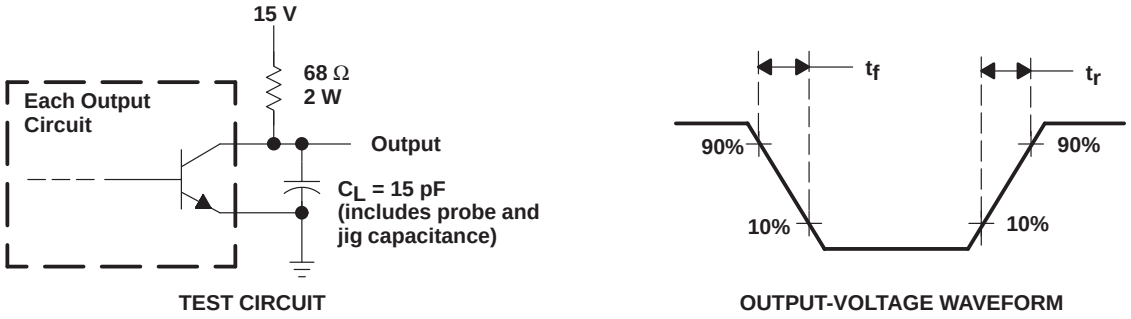



**Figure 2. Operational Test Circuit and Waveforms**

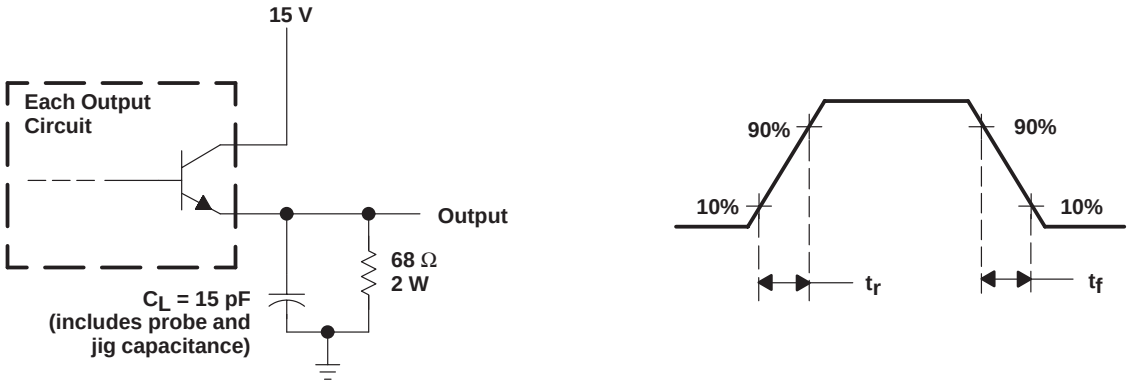
## PARAMETER MEASUREMENT INFORMATION




TEST CIRCUIT

OUTPUT-VOLTAGE WAVEFORM

**Figure 3. Common-Emitter Configuration**



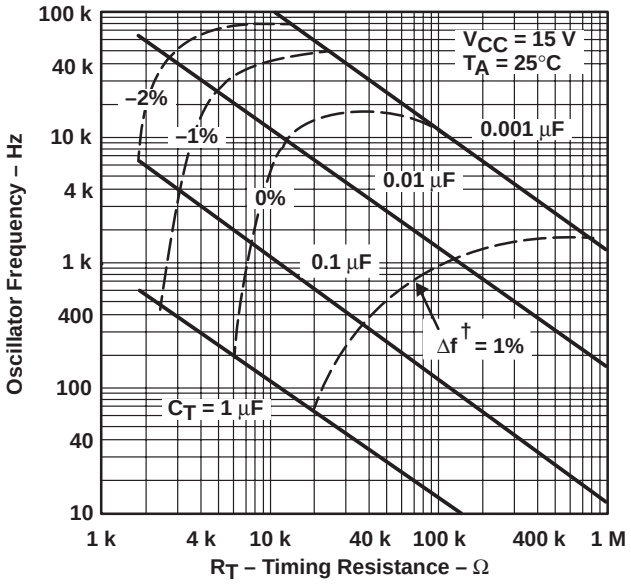

TEST CIRCUIT

OUTPUT-VOLTAGE WAVEFORM

**Figure 4. Emitter-Follower Configuration**

## TYPICAL CHARACTERISTICS

**OSCILLATOR FREQUENCY AND FREQUENCY VARIATION† vs TIMING RESISTANCE**




† Frequency variation (Δf) is the change in oscillator frequency that occurs over the full temperature range.

**Figure 5**

**AMPLIFIER VOLTAGE AMPLIFICATION vs FREQUENCY**

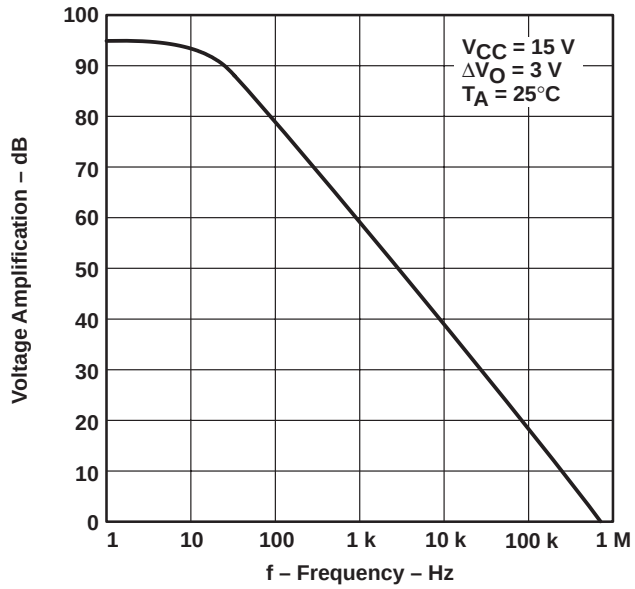



**Figure 6**

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