Serial Digital Video and Interface RAPIDESIGNER© Operation and Applications Guide

INTRODUCTION

The National Semiconductor Serial Digital Video and Interface RAPIDESIGNER© makes quick work of calculations frequently used in the designs using National's Comlinear CLC-series of SMPTE 259M serial digital video components and other serial data transmission products on printed circuit boards. Based on principles contained in the CLC-series data sheets and the *Interface Databook*, the Serial Digital Video and Interface RAPIDESIGNER benefits from our many years experience in designing and manufacturing data transmission and interface products and from helping our valued customers obtain the most from National's Interface products.

If you would like information about other National Semiconductor products, please contact one of our Customer Response Centers: 1-800-272-9959 (USA), 49-0-180-532-78-32 (Europe), or 81-043-299-2308 (Japan). Our *Worldwide Web* site is: http://www.national.com. For applications assistance on Interface products, call our Interface Applications Hotline, 1-408-721-8500 in Santa Clara, CA, USA.
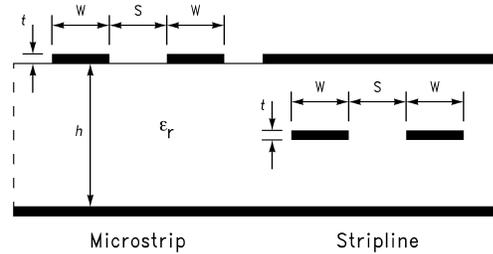
CAUTIONARY STATEMENT

National Semiconductor assumes no responsibility and accepts no liability for results obtained or application of these results from the use of the Serial Digital Video and Interface RAPIDESIGNER. In order to obtain meaningful and useable results from this calculator, the user must be familiar with RF design techniques, PLL design, general transmission line theory and the application and analysis of transmission lines with pulse excitation.

The resolution of results obtainable from the Serial Digital Video and Interface RAPIDESIGNER is similar to that of most common Napierian sliderules, that being two to three significant digits. The accuracy of results from the sliderule depends on the relationships of the numerical factors as inputs and the approximations used for the calculations. Accuracy limits and restrictions for approximations and calculations is given in Appendix A, if known.

TRANSMISSION LINE GEOMETRY

Microstrip and stripline geometries as used in the Serial Digital Video and Interface RAPIDESIGNER are defined as shown below. In common practice, h represents dielectric thickness for microstrip structures and b that for stripline. For simplicity, the Serial Digital Video and Interface RAPIDESIGNER uses only h to represent dielectric (substrate) thickness. Stripline structures treated by the RAPIDESIGNER are symmetrical and differential lines are edge-coupled only.

Microstrip   Stripline

AN100931-1

REACTANCE FREQUENCY (SIDE ONE)

The reactance frequency scales are used to find capacitive reactance X_C, capacitance C, or frequency f, given any two of these parameters. Similarly, inductive reactance X_L, inductance L, or frequency f, may be found on the appropriate scales. In addition, the value of capacitance and inductance that are resonant at a given frequency may be found.

EXAMPLES

1. Find the capacitance value that will give 0.2Ω reactance at 50 MHz.
    A. Set 50 MHz on the Frequency scale opposite the arrow.
    B. Opposite 0.2Ω on the Capacitive Reactance scale, read 17 nF on the Capacitance scale.
2. Find the frequency at which 25 nH will have 10Ω reactance.
    A. Set 0.025 µH (25 nH) on the Inductance scale opposite 10Ω on the Inductive Reactance scale.
    B. Read 63 MHz on the Frequency scale at the arrow.
3. Find the capacitance value that will be resonant with 20 mH at 100 kHz.
    A. Set 100 kHz on the Frequency scale at the arrow.
    B. Opposite 20 mH on the Inductance scale, read 13 kΩ on the Inductive Reactance scale.
    C. Opposite 13 kΩ on the Capacitive Reactance scale, read 130 pF on the Capacitance scale. (The hand-calculated value is 127 pF.)

DIFFERENTIAL Z_0 (SIDE ONE)

This set of scales finds the approximate characteristic impedance of edge-coupled, differential-pair microstrips or striplines. Before using these scales, the characteristic impedance Z_0, of the individual conductor must first be found using the **Microstrip and Stripline Z_0** scales on Side Two. Next, the differential impedance, Z_{diff}, is found based on the line spacing, s, and dielectric thickness, h. Both conductors of the pair must have the same physical cross sectional dimensions. Spacing between pairs of differential conductors should be greater than 2s to avoid excessive crosstalk between and avoid affecting the impedance of adjacent line structures.

The formulations and computational method used are unique to the Serial Digital Video and Interface RAPIDE-SIGNER. The computation is based on an approximation of the reverse-crosstalk parameter of a coupled line pair. It has been shown[1–6] that this parameter can be used to express the mutual inductance and capacitance of the line pair. Therefore, the approximate characteristic impedance of the differential pair may be computed.

Note: The range of *s/h* for microstrip is limited to $0.20 \leq s/h \leq 3.0$. The range of *s/h* for stripline is $0.20 \leq s/h \leq 1.5$.

1. H.R. Kaupp, "Pulse Crosstalk Between Microstrip Transmission Lines", *7th International Electronic Circuit Symposium Record.* Aug. 1966, Wescon.

2. John A. DeFalco, "Predicting Crosstalk in Digital Systems". *Computer Design,* June 1973, p.p. 69–75.

3. H.R. Kaupp, "Effects of Embedding Microstrip Interconnections", *Proceedings International Electronic Packaging and Production Conference* (Inter/Nepcon 69), Oct. 1969, p.p. 189–201.

4. N.C. Arvanitakis, J.T. Kolias, and W. Radzelovage, "Coupled Noise Prediction in Printed Circuit Boards for a High-Speed Computer System", *7th International Electronic Circuit Symposium Record,* Aug. 1966, Wescon.

5. A. Feller, H.R. Kaupp and J.J. Digiacomo, "Crosstalk and Reflections in High-Speed Digital Systems", *Proceedings — Fall Joint Computer Conference,* 1965, p.p. 511–525.

6. Ivor Catt, "Crosstalk (Noise) in Digital Systems", *IEEE Transactions on Electronic Computers,* Vol. EC-16, No. 6, Dec. 1967, p.p. 743–763.

EXAMPLE

1. Find the differential impedance for an edge-coupled pair of 75Ω microstrips spaced 10 mils apart on a 20 mils thick substrate.

    A. Move slide to set 10 mils on the s-scale at 20 mils on the h-scale (upper window).

    B. Read 0.702 on the Microstrip Factor scale at the arrow (middle window).

    C. Move slide to set 75Ω on the Z_0 scale opposite 0.702 on the Factor scale (lower window).

    D. Read 105Ω on the Z_{diff} scale at arrow.

RETURN LOSS (SIDE ONE)

These scales calculate the return loss when line impedance, Z_0, and source or load impedance are known. The return loss is always a positive number.

EXAMPLE

1. Find the return loss when a 50Ω transmission line is terminated in 75Ω.

    A. Move slide to set the 50Ω transmission line impedance at the arrow.

    B. Read 14 dB return loss at the 75Ω load resistance.

MICROSTRIP AND STRIPLINE Z_0

These Microstrip and Stripline Z_0 scales calculate the characteristic impedance of microstrip or stripline transmission lines.

In solving microstrip and stripline problems, the Serial Digital Video and Interface RAPIDESIGNER uses separate scale sets based on the conductor thickness, t. The values for t are the standard thicknesses for copper cladding used in printed circuit board material manufacture given in common oz/ft^2 values.

The two most common uses of these scales are to find:

1. impedance Z_0, given line width w, dielectric thickness h, conductor thickness t, and dielectric constant ϵ_r; or

2. line width w given the other factors.

The procedures given in the following examples are the same for either microstrip or stripline. Of course, the Factor and Z_0 scales appropriate to the particular line type must be used.

EXAMPLES

1. Find the conductor line width to yield a 93Ω microstrip on a 30 mil substrate with 0.7 mil (½ oz) copper cladding and dielectric constant of 3.8.

    A. Move slide to set 93Ω on the Microstrip Z_0 scale opposite 3.8 on the ϵ_r scale directly below.

    B. Read +25 on the Microstrip Factor scale at the arrow.

    C. Move slide to set 30 mils on the h-scale at the arrow, top window.

    D. At the window and scale for t = 0.7 mils (½ oz), read 19 mils on the w-scale opposite +25 on the Factor scale directly above.

2. Find the impedance of a 25 mils wide microstrip conductor on a substrate with ϵ_r = 4.3, t = 1.4 mils (1 oz cu.) and h = 20 mils.

    A. Move slide to set 20 mils on the h-scale at the upper arrow, top section.

    B. In the section for t = 1.4 mils (1 oz) opposite 25 mils on the w-scale, read –17 on the Factor scale directly below.

    C. Move slide to set –17 on the Microstrip Factor scale at the arrow in middle window.

    D. Read 65Ω on the Microstrip Z_0 scale opposite 4.3 on the ϵ_r scale directly below.

INTRINSIC DELAY (SIDE TWO)

This scale calculates the per unit-length propagation delay of a wave traveling on an unloaded microstrip or stripline transmission line.

EXAMPLE

1. Find the delay of a stripline with ϵ_r = 4.5.

    A. Move slide to set 4.5 on the Stripline ϵ_r scale at the upper arrow.

    B. Read 142 ps/in on the T_d scale at the lower arrow.

CLC016 DESIGN FACTORS (SIDES THREE AND FOUR)

These scales aid the designer in selecting component values which govern operation of the CLC016 Data Retiming PLL. Reference should also be made to the data sheet for the CLC016 for a more complete explanation of its operation.

VCO FREE-RUNNING FREQUENCY (SIDE FOUR)

The CLC016's VCO free-running frequency is determined by resistor values connected to pins R_0 through R_3. The graduations and numbering of the RAPIDESIGNER's Rn scale are in standard 1% resistor values. This simplifies choosing the standard 1% resistor value required for each frequency.

EXAMPLE

1. Find the resistor value that will set the VCO free-running frequency to 270 Mbps.
    A. Move the slide to set 270 Mbps at the upper arrow.
    B. Read 3,480Ω at the lower arrow.

LOOP BANDWIDTH (SIDE THREE)

The low-pass filter's fractional loop bandwidth is determined by the choice of f_{BW}, f_{DATA}, data transition density, ρ, and resistor, R_{BW}. The fractional loop bandwidth, λ_{BW}, is determined by the ratio of f_{BW} to f_{DATA}. The value of resistor, R_{BW}, is a function of the fractional loop bandwidth, λ_{BW}, and the data transition density, ρ.

EXAMPLES

1. Find the fractional loop bandwidth and bandwidth setting resistor, R_{BW}, for a fractional loop bandwidth of 1 MHz, a data rate of 270 Mbps and data transition density of 0.5.
    A. Move the slide to set 1 MHz on the f_{BW} scale opposite 270 Mbps on the f_{DATA} scale in the upper window.
    B. Read 0.0037 (0.37%), the fractional loop bandwidth at the arrow in the same window.
    C. Without moving the slide, read 681Ω (nearest standard 1% value) for R_{BW} opposite $\rho = 0.5$ in the lower window.

2. Find the fractional loop bandwidth and bandwidth setting resistor, R_{BW}, for a fractional loop bandwidth of 650 kHz a data rate of 270 Mbps and data transition density of 0.5.
    A. Move the slide to set 650 kHz on the f_{BW} scale opposite 270 Mbps on the f_{DATA} scale in the upper window.
    B. Read 0.0024 (0.24%), the fractional loop bandwidth at the arrow in the same window.
    C. Without moving the slide, read 499Ω (nearest standard 1% value) for R_{BW} opposite $\rho = 0.5$ in the lower window.

JITTER PEAKING AND ACQUISITION TIME (SIDE THREE)

The jitter peaking factor, δ, is determined by the choices of frequencies f_Z and f_{BW}. The ratio of these frequencies determines the critical frequency ratio, α, which relates the jitter peaking factor, δ, to the previously found value of R_{BW}, thus allowing the value of the loop filter capacitor, C_Z, to be found.

EXAMPLE

1. Find the critical frequency ratio, jitter peaking factor, loop filter capacitor, C_Z, and the acquisition time estimate for Example 2 in the preceeding section (a fractional loop bandwidth of 650 kHz a data rate of 270 Mbps) if 0.05 dB of jitter peaking can be tolerated.
    A. Move the slide to set 0.05 on the Jitter Peaking Factor scale opposite the lower arrow in the window
    B. Read 0.007 on the Critical Frequency Ratio scale at the upper arrow in the same window.
    C. Without moving the slide, read 4.5 kHz on the f_Z scale opposite 650 kHz on the f_{BW} scale in the upper window.
    D. Move the slide to set 0.007 on the Critical Frequency Ratio scale in the middle window opposite 650 kHz on the f_{BW} scale in the same window.
    E. Read 70 nF (68 nF closest standard value) on the C_Z scale opposite 500Ω on the R_{BW} scale in the same window.
    F. Move the slide to set 70 nF on the C_Z scale opposite 270 Mbps on the f_{DATA} scale in the lower window.
    G. Read 2 ms on the Acquisition Time scale at the arrow in the same window.

CAPACITANCE C_P (SIDE THREE)

The loop filter capacitor, C_P, affects the amount of jitter and its peaking value. It can also affect the ability of the loop to acquire lock.

EXAMPLE

1. Continuing with the values used in the preceeding example, find the value of C_P.
    A. Move the slide to set 500Ω on the R_{BW} scale opposite 650 kHz on the f_{BW} scale
    B. Read 120 pF on the C_P scale at the arrow in the same window.

VECTOR IMPEDANCE (SIDE FOUR)

These scales evaluate the relationship between a network's resistance (R_S), reactance (X), impedance (Z), phase angle (θ) and Q (Tan θ). Both R-C and R-L circuits are handled.

EXAMPLE

1. If the impedance of a network is 50Ω and the real part is 25Ω. Find the reactive component, phase angle and circuit Q.
    A. Move the slide to set 50Ω on the Impedance scale at the arrow.
    B. Opposite 25Ω on the Resistance scale, read 60° on the Phase Angle scale in the same window.
    C. Without moving the slide, read 43.3Ω on the Reactance scale opposite 60° on the Phase Angle scale in the lower window.
    D. Without moving the slide, read 1.7 on the Q scale opposite 43.3Ω on the Reactance scale in the same window.

THEVENIN EQUIVALENT TERMINATIONS (SIDE FOUR)

These scales compute the resistances which, when connected from the transmission line's receiving end to the positive power supply terminal and the negative supply terminal, provide the equivalent termination resistance, R_T, and voltage, V_T, to that of a single resistor connected to a termination voltage supply. The corresponding resistances have been given the nomenclature R_{VCC} and R_{VEE} to signify the resistance connected from the V_T node to the most-positive supply terminal and the most-negative terminal, respectively, regardless of supply polarity.

The RAPIDESIGNER handles two situations with respect to the polarities of supplies V_S and V_T: 1) the signs of both V_S and V_T are positive or 2) both are negative. Appropriate R_{VCC} and R_{VEE} scales give correct resistor values for both conditions. When using these scales, pay close attention to the correct scale being used for the supply polarities being used. The RAPIDESIGNER cannot solve the situation where supplies have mixed polarities. These situations can be evaluated by transforming the supply values to an all-positive or all-negative supply situation.

EXAMPLES

1. Find the resistances which, connected across a +5V supply, will give a Thevenin equivalent voltage of +3V and resistance of 75Ω.

    A. Move the slide to set 3 on the V_T scale opposite 5 on the V_S scale in the upper, left-hand window..

    B. Read 2.5 on the Factor scale at the arrow in the same window.

    C. Move the slide to set 2.5 on the Factor scale opposite 75 on the Equivalent Termination Resistance scale in the lower window.

    D. Read 187Ω (nearest 1% value) on the R_{VEE} scale (for positive values of V_S and V_T) at the arrow.

    E. Move the slide to set 5 on the V_S scale opposite 3 on the V_T scale in the right-hand window.

    F. Read 124Ω (nearest 1% value) on the R_{VCC} scale (for positive values of V_S and V_T) opposite 75Ω on the Equivalent Termination Resistance scale in the same window.

2. Find the resistances which, connected across a −5.2V supply, will give a Thevenin equivalent voltage of −2.0V and resistance of 50Ω.

    A. Move the slide to set 2 on the V_T scale opposite 5.2 on the V_S scale in the upper, left-hand window.

    B. Read 1.6 on the Factor scale at the arrow in the same window.

    C. Move the slide to set 1.6 on the Factor scale opposite 50Ω on the Equivalent Termination Resistance scale in the lower window.

    D. Read 80.6Ω (nearest 1% value) on the RV_{CC} scale (for negative values of V_S and V_T) at the arrow.

    E. Move the slide to set 5.2 on the V_S scale opposite 2 on the V_T scale in the right-hand window.

    F. Read 130Ω (nearest 1% value) on the R_{VEE} scale (for negative values of V_S and V_T) opposite 50Ω on the Equivalent Termination Resistance scale in the same window.

APPENDIX A — SCALE FORMULATIONS

REACTANCE FREQUENCY

$$X_C = \frac{1}{2\pi fC} \; Ohms$$

$$X_L = 2\pi fL \; Ohms$$

DIFFERENTIAL Z_0

For microstrip line the differential impedance, Z_{diff}, is:

$$Z_{diff} \cong 2Z_0 \left(1 - 0.48e^{-0.96\frac{s}{h}} \right) \textbf{Ohms.}$$

For stripline the differential impedance, Z_{diff}, is:

$$Z_{diff} \cong 2Z_0 \left(1 - 0.374e^{-2.9\frac{s}{h}} \right) \textbf{Ohms.}$$

Note: These functions were derived from empirical data. The actual accuracy has not been determined experimentally. Various sources cite possible errors of up to ±10%. The practical ranges for Z_0 and Z_{diff} are from 20Ω to about 150Ω.

RETURN LOSS

$$R.L. = 20 \times \log_{10} \left| \frac{R_{L(S)} + Z_0}{R_{L(S)} - Z_0} \right| dB$$

Where:

$R_{(LS)}$ = load (or source) resistance in Ω (Ohms).

Z_O = transmission line impedance in Ω (Ohms).

MICROSTRIP AND STRIPLINE Z_0

Microstrip characteristic impedance is:

$$Z_0 = \frac{60}{\sqrt{0.475\epsilon_r + 0.67}} \; \ln\left[\frac{4h}{0.67\,(0.8w + t)} \right] Ohms.$$

If $w \leq 2h$ (maximum error $\cong$ 3%).

Microstrip line width is:

$$w = \frac{7.463h}{\exp\left(\frac{Z_0\sqrt{0.475\epsilon_r + 0.67}}{60} \right)} - 1.25t \; mils$$

Where: w = trace width in mils., t = trace thickness in mils, *h* = dielectric thickness in mils., ϵ_r = relative dielectric constant (dimension less). **Note:** All geometric variables must be in the same dimensional units.

Stripline characteristic impedance is:

$$Z_0 = \frac{60}{\sqrt{\epsilon_r}} \; \ln\left[\frac{4b}{0.67\pi\,(0.8w + t)} \right] Ohms.$$

Best accuracy results if parameters are kept within these guiding ratios: b − t > 2w and b > 4t.

Stripline line width is:

$$w = \frac{2.375b}{\exp\left(\dfrac{Z_0\sqrt{\epsilon_r}}{60}\right)} - 1.25t \text{ mils}$$

Where: b = dielectric thickness (between ground planes) in mils. All other variables are as previously defined. **Note:** As for Z_0, guiding ratios apply.

INTRINSIC DELAY

The intrinsic propagation delay for microstrip is:

$$T_d = 84.73\sqrt{0.475\epsilon_r + 0.67} \text{ ps/in.}$$

The intrinsic propagation delay for stripline is:

$$T_d = 84.73\sqrt{\epsilon_r} \text{ ps/in.}$$

Where, ϵ_r = relative dielectric constant (dimensionless).

CLC016 DESIGN FACTORS

VCO FREE-RUNNING FREQUENCY

$$R_n = \frac{10^6}{f_{DATA}} - 200\,\Omega$$

Where: The data rate, f_{DATA}, is given in Mbps.

LOOP BANDWIDTH

$$\lambda_{BW} = \frac{f_{BW}}{f_{DATA}}$$

$$R_{BW} = \frac{104.7 \times 10^3 \lambda_{BW}}{\rho} \,\Omega$$

Where: The data rate, f_{DATA}, is given in Mbps, the loop bandwidth, f_{BW}, is given in Hz and the data transition density, ρ. is a number between 0.1 and 1.0.

JITTER PEAKING AND ACQUISITION TIME

$$\alpha = \frac{f_Z}{f_{BW}} \cong \delta(0.134 + 0.058\delta)$$

$$C_Z = \frac{0.1592}{\alpha R_{BW} f_{BW}} \text{ capacitance units}$$

$$t_{ACQ} \leq \frac{C_Z}{0.14\,\text{pF} \times f_{DATA}\,(\text{Mbps}) \times 10^6} \text{ time units}$$

CAPACITANCE C_P

$$C_P = \frac{0.0398}{R_{BW} f_{BW}} \text{ capacitance units}$$

VECTOR IMPEDANCE

$$Z^2 = R_S{}^2 + X^2 \text{ Ohms } (\Omega).$$

$$\tan\Theta = \frac{X}{R_S} \text{ degrees.}$$

$$Q = \tan\Theta \text{ (dimensionless)}$$

THEVENIN EQUIVALENT TERMINATIONS

For positive (supply voltage) values of V_S and V_T:

$$R_{V_{CC}} = R_T \times \left(\frac{V_S}{V_T}\right)\Omega$$

$$R_{V_{EE}} = R_T \times \left(\frac{V_S}{V_S - V_T}\right)\Omega$$

For negative (supply voltage) values of V_S and V_T:

$$R_{V_{CC}} = R_T \times \left(\frac{V_S}{V_S - V_T}\right)\Omega$$

$$R_{V_{EE}} = R_T \times \left(\frac{V_S}{V_T}\right)\Omega$$

Notes

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