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# D E S I G N E R N O T E S

# C-Bus Voltage Calculation

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# Synopsis:

The guidelines used by installers to determine whether a C-Bus Network design is within specifications are sometimes not adequate to cover more complex cases.

This Design Note provides formulas that can be applied to a network design to determine the voltage drops across the network.

## Introduction

Most C-Bus installers are familiar with the general guidelines of installing C-Bus to ensure that the C-Bus voltage is sufficient:

- No more than 100 units per network
- No more than 1000m of cable
- Make sure there are enough power supplies for the units

Unfortunately, these simple guidelines are not sufficient to completely predict whether a C-Bus network will have adequate voltage at all points on the network.

In the following examples it is assumed that there are sufficient C-Bus power supplies for the C-Bus units used (the C-Bus Calculator will provide this information).

For a long network with lots of C-Bus units, like the one in Figure 1, there may be considerable voltage drop along the C-Bus cable.

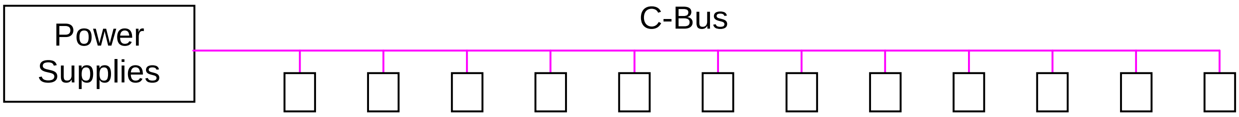


**Figure 1**

For the case of 100 C-Bus input units spaced at 3m intervals along a C-Bus cable, the voltage along the network is shown in Figure 2.

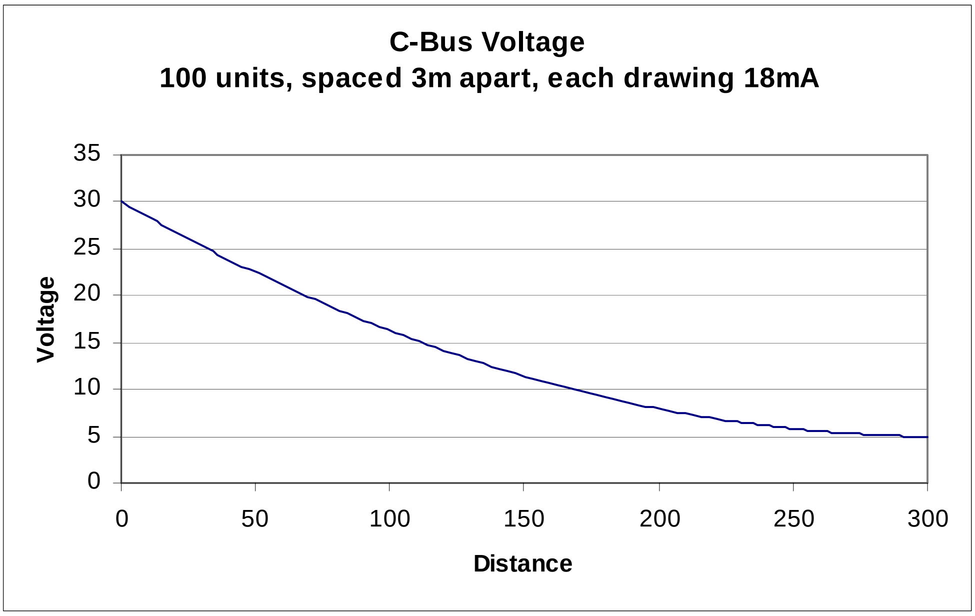


**Figure 2**

The voltage at the far end of the network is around 5V, which will prevent the network from operating correctly, even though the simple guidelines have been followed.

It should be noted that adding more power supplies to the network at the same place as the others will <u>not</u> make any difference to the network voltages and will <u>not</u> solve the problem.

There are generally two solutions to the problem :

1. Spread the power supplies around the network
2. Spread the network around the power supplies

## Spreading the Power Supplies Around the Network

By placing ½ of the power supplies at each end of the network (as shown in Figure 3), the voltage drops are reduced considerably. For the above example of 100 units at 3m intervals, the voltage along the network is shown in Figure 4. Voltages are well within the C-Bus operational limits.

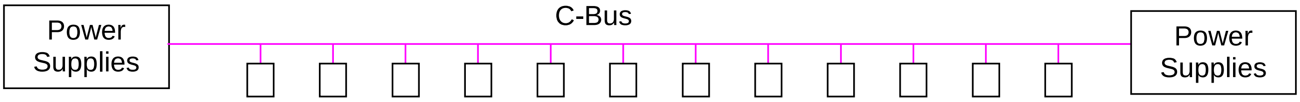


**Figure 3**

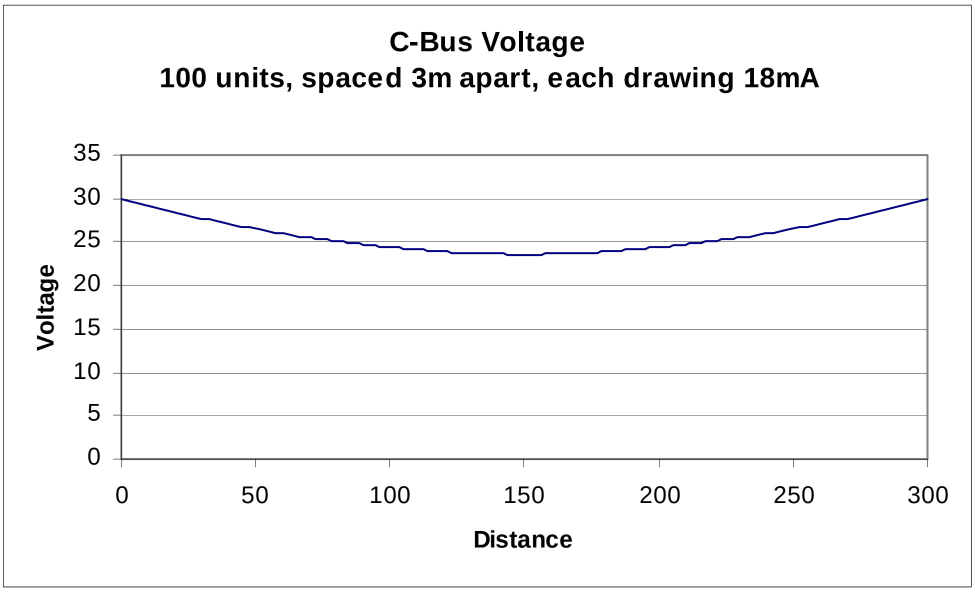


**Figure 4**

Placing power supplies at additional points along the network will improve the voltage again. It is not always convenient or possible to spread the power supplies around the network. In these cases, it may be possible to spread the network around the power supplies.

## Spreading the Network Around the Power Supplies

By placing ½ of the network on each side of the Power Supplies (as shown in Figure 5), the voltage drops are also reduced considerably. For the above example of 100 units at 3m intervals, split into two separate runs, the voltage along the network is shown in Figure 6.

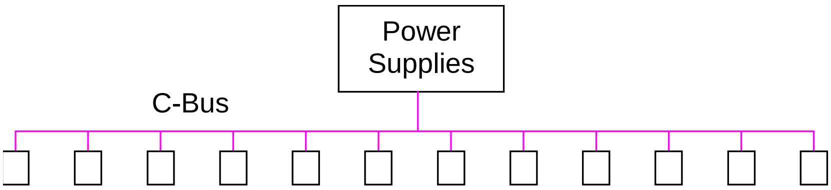


**Figure 5**

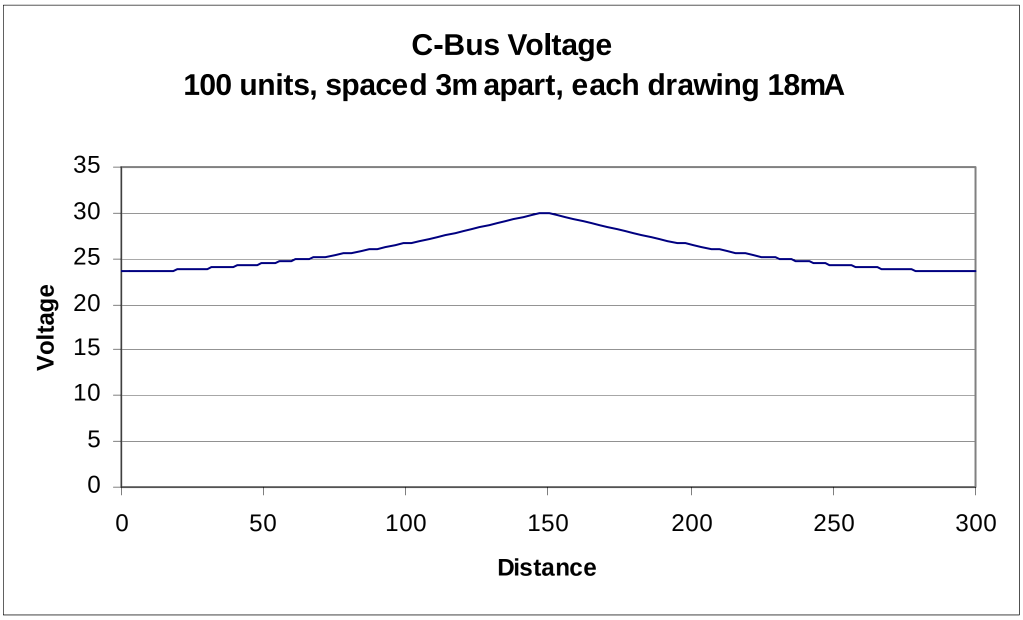


**Figure 6**

Dividing the network into additional runs will improve the voltage again. A comparison of the network voltages for the above example with a single network run, and with the network divided into 2, 3 and 4 runs is shown in Figure 7.

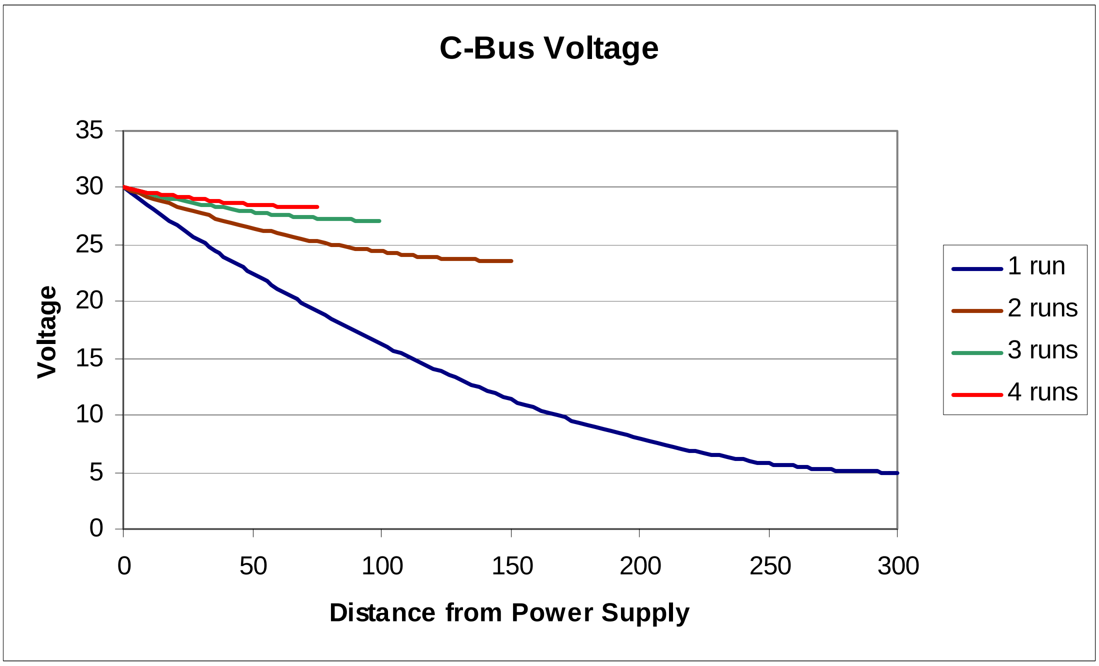


**Figure 7**

## Calculating Voltage Drops

The voltage at the end of a C-Bus Network with power supplies at one end and where the units are evenly spaced and have the same current consumption is found from:

$$Vend = 36 - \frac{I\ N\ R}{p} - 0.045\ L\ I\ \ (n+1)$$

$$Vend \approx 36 - (\frac{R}{p} + 0.045\ L)\ I\ n$$ (for n > 10 with a single run)

Where : $V_{end}$ = voltage at end of network

L = length of C-Bus network

I = current per unit (18mA for key input units)

n = number of C-Bus units on the run

N= total number of C-Bus Units on all runs

R = output impedance of Power Supplies (see Table 1)

p = number of Power Supplies

### Notes on applying the formula:

Where the network is spread around the power supplies, the above formula should be applied to each run to determine whether the voltages are within range.

Where the power supplies are spread evenly around the network, the formula can still be used. In this case, the half way point between two power supplies is like the end of a run. The voltage will be given by using the formula with half of the number of units (on the run between the two power supplies) and half the length of the cable between the power supplies.

Where the units have different currents, use an average value. The calculated result in these cases will be less accurate.

In an installation where most or all of the units are at the far end of a network (rather than being evenly distributed) the end voltage will be lower than the formula predicts. If the units are mostly closer to the power supplies, the end voltage will be higher.

| C-Bus Power Supply | Output Impedance |
|---|---|
| 5500PS (350mA) | 20Ω |
| Din Rail Output Units with 200mA power supply | 35Ω |

**Table 1**

## Example Calculations

### Example 1

If you have 100 input units, 3 meters apart, each drawing 18mA (as for the original example):

L = 300m

n = 100

N = 100

I = 0.018A (18mA)

R = 20 (assuming DIN rail power supplies)

p = 6 (6 x 350mA = 2100mA)

$V_{end}$ = 36 – (20 / 6 + 0.045 x 300) x 0.018 x 100 (using approximation formula)

= 5.7V (this network is not OK)

### Example 2

If you have 8 touch screens spread over a 1000 meter long network, each drawing 40mA:

L = 1000m

n = 8

N = 8

I = 0.040A (40mA)

R = 20 (assuming DIN rail power supplies)

p = 2 (2 x 350mA = 700mA)

$V_{end}$ = 36 – 20 / 2 x 8 x 0.04 – 0.045 x 1000 x 0.040 x 9

= 16.6V (this network is just OK, but should be improved)

### Example 3

If you have 3 touch screens and 20 key input units on a network which is 200m long:

L = 200m

n = 23 (3 + 20)

N = 23

I = 0.029A (average value = (40mA x 3 + 18mA x 20) / 23 )

R = 20 (assuming DIN rail power supplies)

p = 2 (2 x 350mA = 700mA)

$V_{end}$ = 36 – 20 / 2 x 23 x 0.029 – 0.045 x 200 x 0.029 x 24

= 23V (this network is OK)

### Example 4

If you have 100 input units, 3 meters apart, each drawing 18mA, but with a power supply at each end:

L = 150m (use half the network length where power supplies are spread around)

n = 50 (use half the number of units where power supplies are spread around)

N = 100 (there are 100 units in total)

I = 0.018A (18mA)

R = 20 (assuming DIN rail power supplies)

p = 6 (6 x 350mA = 2100mA)

$V_{end}$ = 36 – 20 / 6 x 100 x 0.018 – 0.045 x 150 x 0.018 x 51

= 23.8V (this network is OK)

### Example 5

By rearranging the formula in the Appendix, the relationship between the number of input units and the length of cable on a single run is:

$$n = \frac{V_s - V_{end}}{0.045\,L\,I} - 1 \quad \text{and} \quad L = \frac{V_s - V_{end}}{0.045\,I\,(n+1)}$$

This is shown graphically in Figure 8 assuming:

$V_s$ = 32V (typical case where the number of power supplies is just adequate)

$V_{end}$ = 18V (allowing a few volts of margin)

I = 18mA

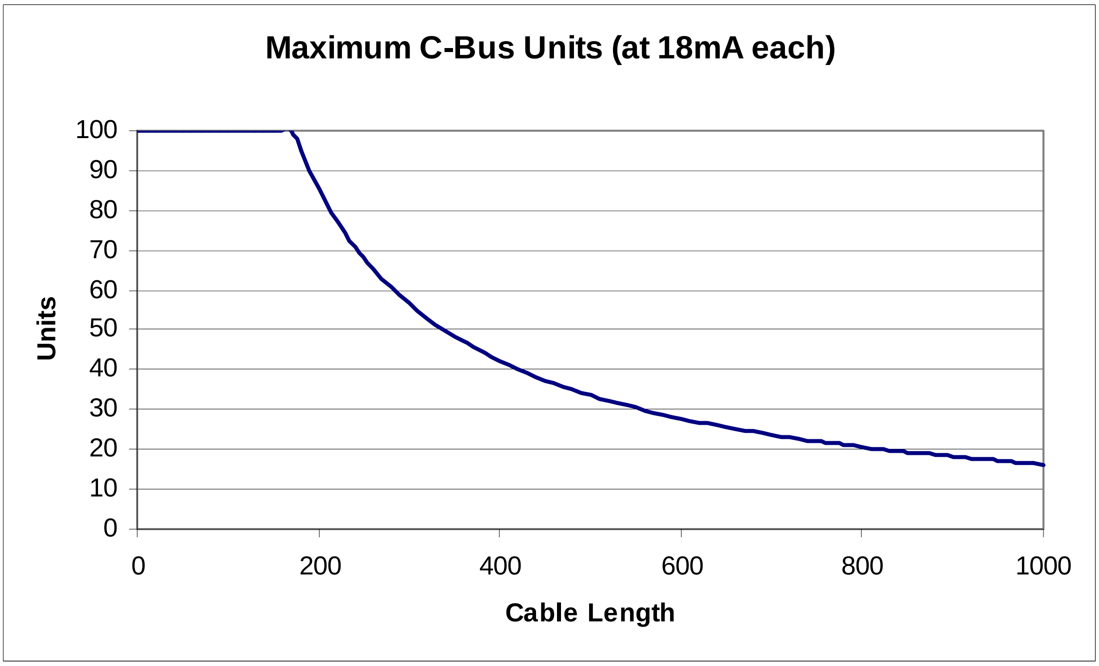


**Figure 8**

## Conclusions

It is possible to determine the approximate voltage at the end of a C-Bus network.

Provided the end voltage is within the C-Bus operational voltage range (15V – 36V), the network should operate satisfactorily.

It is always best to allow a few volts of margin to allow for errors, so if the formula predicts a voltage of less than 20V, it is advisable to consider restructuring the network.

Where the approximations do not hold (for example, there are units of different currents, their spacing is uneven or there are different types of power supplies), then averages can be used. In this case the result will be less accurate, and a wider “safety factor” should be applied (for example, if the result is less than 24V, then the network could have a problem).


**Caution : Maths Ahead**

The voltage drops along a C-Bus network can be calculated using ohms law:

$V = I\,R$

Where V = voltage drop

I = current

R = resistance

However, this gets a bit complicated when there are multiple C-Bus devices placed along a network as in the examples above. In this case, the voltages are calculated as given below.

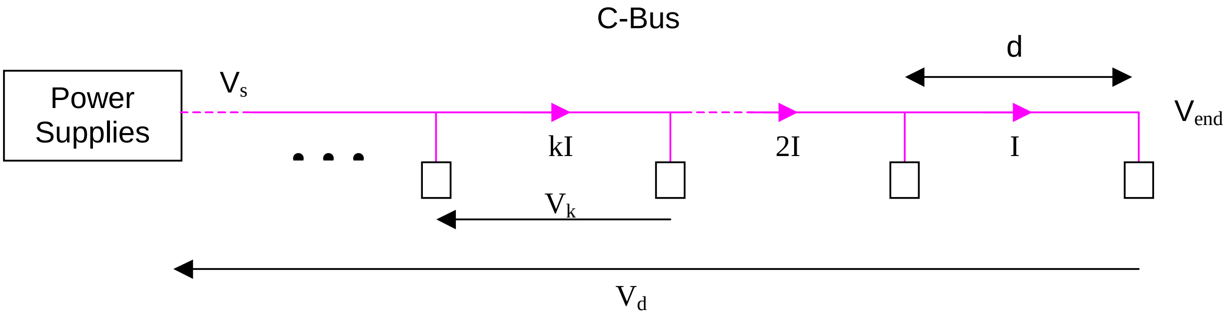


**Figure 9**

Assuming (see Figure 9):

- evenly spaced units (distance d apart)
- all units drawing the same current (I)

The voltage at the end of the network is equal to the power supply voltage minus the voltage drop:

$$V_{end} = V_s - V_d$$

## Voltage Drop

The voltage drop is found from :

$$V_d = \sum_{k=1}^{n} V_k$$

where n is the number of units on the run.

The voltage drop between each unit is the current (k I) x the resistance (R), giving:

$$V_d = \sum_{k=1}^{n} k\ I\ R$$

$$V_d = I\ R\sum_{k=1}^{n} k$$

$$V_d = I\ R\,\frac{1}{2}n(n+1)$$

The resistance of C-Bus cable (with pairs wired together) is around 0.09Ω/m, so

$$V_d = 0.045\, d\ I\ n(n+1)$$

The total length of the cable

L = n d

Hence

$$V_d = 0.045\, L\ I\ (n+1)$$

For values of n greater than 10, the approximation can be used:

$$Vd \approx 0.045\, L\ I\ n$$

## Power Supply Voltage

The nominal Power Supply voltage for a single power supply is:

$$V_s = 36 - I_o R_o$$

Where $I_o$ = output current

$R_o$ = output impedance

The output impedance for various C-Bus Power Supplies are shown in Table 1.

Where there are several power supplies in parallel, the effective impedance will be:

$$\frac{1}{R_o} = \sum_{k=1}^{p} \frac{1}{R_k}$$

Where $R_k$ is the output impedance of the kth power supply

p is the number of power supplies

If all of the power supplies are the same, this simplifies to:

$$R_o = \frac{R}{p}$$

Where R is the output impedance of the power supplies.

p is the number of power supplies

The output current $I_o$ is found from:

$$I_o = I\ N$$

Where I = current consumption per C-Bus unit (typically 18mA)

N = total number of C-Bus units (on all runs powered from the Power Supplies)

Hence

$$V_s = 36 - \frac{I\ N\ R}{p}$$

## Output Voltage

Hence the voltage at the end of the network is:

$$Vend = 36 - \frac{I\ N\ R}{p} - 0.045\ L\ I\ \ (n+1)$$

Where there is a single run, n = N, giving:

$$Vend \approx 36 - (\frac{R}{p} + 0.045\ L)\ I\ n$$ (for n > 10 and with a single run)