

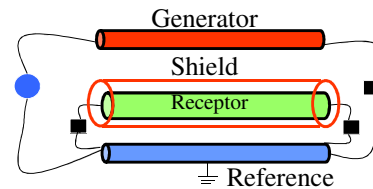
## Techniques to Reduce Crosstalk (Section 9.7.2)

We now consider methods for reducing the crosstalk in a three-conductor line. Suppose the near- or far-end crosstalk in the previous three-conductor line exceeds desired levels, causing interference with the terminations at the ends of the receptor circuit. Obvious ways to reduce that crosstalk:

- A. move the generator and receptor conductors farther apart
- B. route the generator's conductor perpendicular to the receptor's
- C. slow (increase) the pulse rise/fall times of the source to reduce the high frequency spectral content and hence the crosstalk.

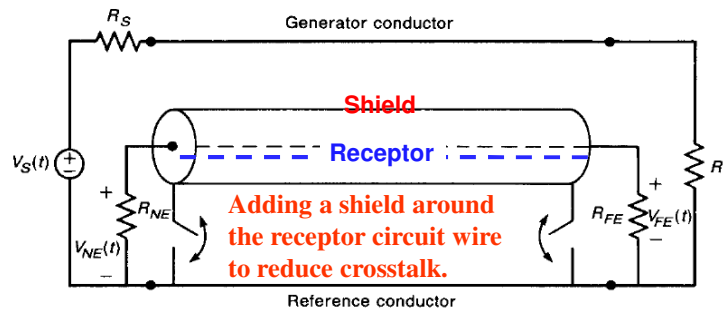
For wire-type lines, there are two common methods for reducing the crosstalk:

- shielded wires or
- twisted wire pairs

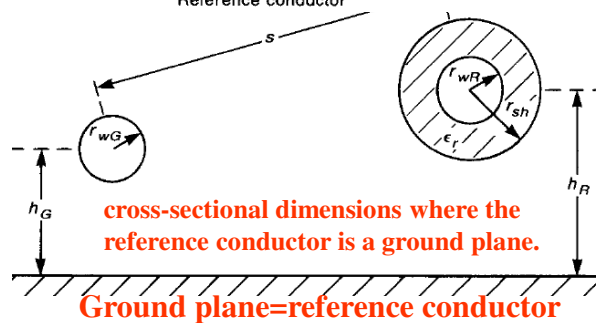


Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

## Techniques to Reduce Crosstalk: I. Shielding the Receptor



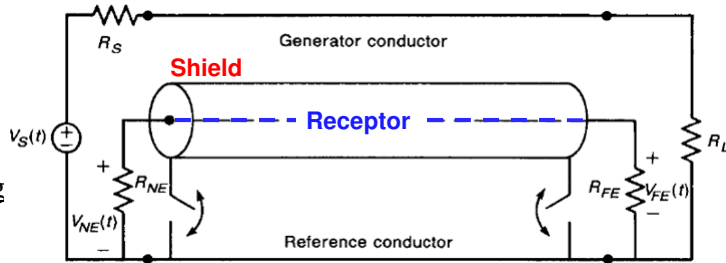
Suppose we surround the receptor wire with a cylindrical shield, as shown.



Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

## Techniques to Reduce Crosstalk: I. Shielding the Receptor

The total crosstalk transfer function is the sum of the inductive and capacitive coupling contributions:



$$\frac{\hat{V}_{NE}}{\hat{V}_S} = \frac{\hat{V}_{NE}^{IND}}{\hat{V}_S} + \frac{\hat{V}_{NE}^{CAP}}{\hat{V}_S}$$

$$\frac{\hat{V}_{FE}}{\hat{V}_S} = \frac{\hat{V}_{FE}^{IND}}{\hat{V}_S} + \frac{\hat{V}_{FE}^{CAP}}{\hat{V}_S}$$

As shown earlier, both contributions depend on the per unit length (PUL) of the conductors.

$$M_{NE}^{IND} = \frac{R_{NE}}{R_{NE} + R_{FE}} \frac{L_m}{R_S + R_L}$$

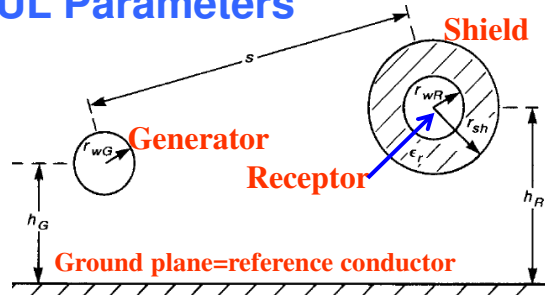
$$M_{NE}^{CAP} = \frac{R_{NE} R_{FE}}{R_{NE} + R_{FE}} \frac{R_L C_m}{R_S + R_L}$$

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

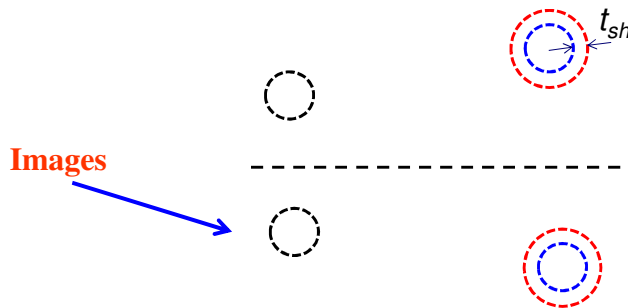
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## Shielded Receptor: PUL Parameters

- The per-unit-length inductance parameters are computed using the flux current methods used earlier.



- Place a current on a conductor and compute the magnetic flux through a coupling circuit and using image theory for the ground plane effect.

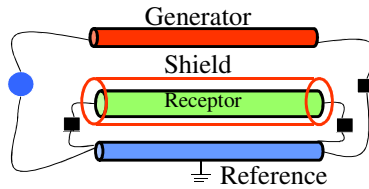


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## Techniques to Reduce Crosstalk” Shielding the Receptor



### A. Capacitive Coupling

- ungrounded shield
- Grounded shield

### B. Inductive Coupling

- ungrounded shield
- Grounded shield

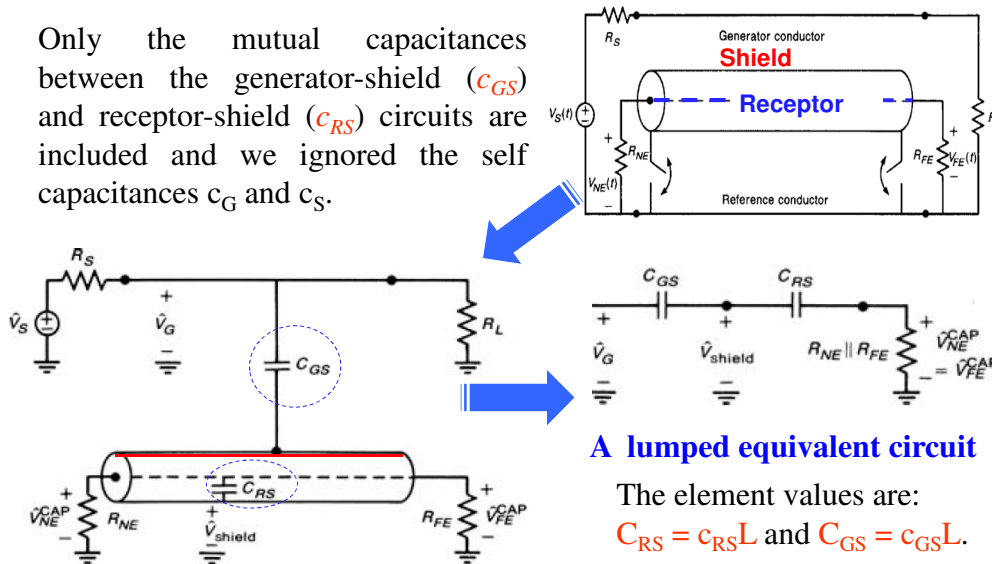
Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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## Shielding the Receptor (Cont.)

### A. Capacitive Coupling (*ungrounded shield*)

Only the mutual capacitances between the generator-shield ( $C_{GS}$ ) and receptor-shield ( $C_{RS}$ ) circuits are included and we ignored the self capacitances  $c_G$  and  $c_S$ .



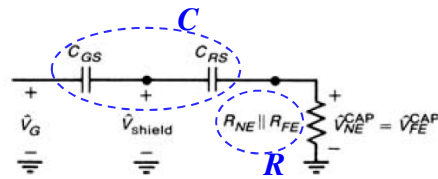
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## Shielding the Receptor (Cont.)

### A. Capacitive Coupling - ungrounded shield

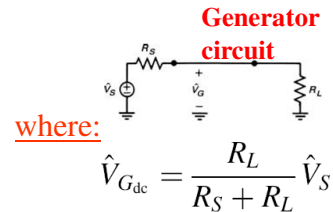
Consider this lumped equivalent circuit



The capacitive coupling, at low frequency, is approximated as:

$$\hat{V}_{NE}^{CAP} = \hat{V}_{FE}^{CAP} \cong V_{G_{dc}} (j\omega RC) / (1 + j\omega RC)$$

$$\cong j\omega \frac{R_{NE} R_{FE}}{R_{NE} + R_{FE}} \frac{C_{RS} C_{GS}}{C_{RS} + C_{GS}} \hat{V}_{G_{dc}}$$



Typically  $C_{RS} \gg C_{GS} \rightarrow C \cong C_{GS} \cong C_{GR}$ , leading to a similar expression as for the unshielded case (see previous cross-talk notes).

**➡ The capacitive coupling is unchanged from the unshielded case.**

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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## Shielding the Receptor (Cont.)

### A. Capacitive Coupling (Cont.) Grounded-Shield

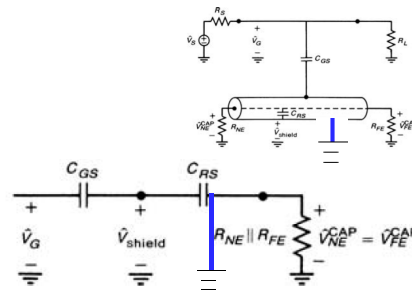
Observe that if the shield is connected to the reference conductor at either end, the shield voltage is reduced to zero and the capacitive coupling contribution is removed:

$$\hat{V}_{NE}^{CAP} = \hat{V}_{FE}^{CAP}$$

$= 0$  the shield is connected to the reference conductor at either end,

➤ A shielded wire eliminates electric field or capacitive coupling.

- For an electrically short line, grounding the shield at either end will cause the voltage all along the shield to be approximately zero.
- **For an electrically long line, ground the shield at multiple points**



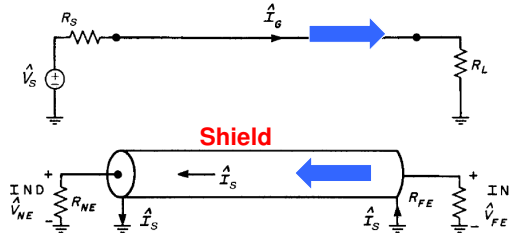
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## Shielding the Receptor (Cont.)

### B. Inductive Coupling:

If the shield is grounded at both ends, then there is a path for a secondary current,  $I_s$ , to flow back along the shield.

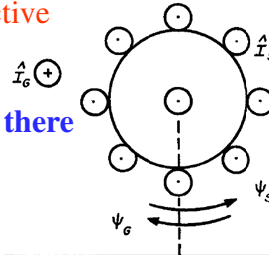


$I_s$  generates a magnetic flux through the shield-ground plane loop that counter-acts the flux due to the generator wire loop ( $I_G$ ) (Faraday's law):

- If the shield is grounded at both ends, the inductive coupling is reduced but not eliminated.

If the shield is not grounded at both ends, then there is no path for  $I_s$  to flow back along the shield.

- If the shield is not grounded at both ends, inductive coupling will not be eliminated



Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

## I. Shielding the Receptor (Cont.)

### B. Inductive Coupling (Cont.)

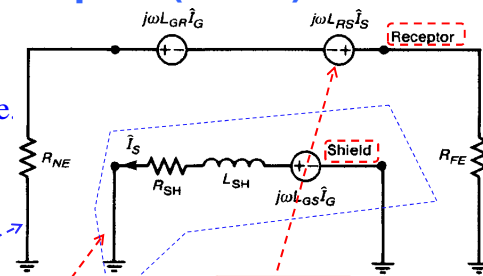
Consider the inductive equivalent circuit for the shielded receptor wire.

The current in the generator circuit induces two emf (voltage) sources

1. The receptor wire-ground plane loop,
2. The shield-ground plane loop which produces the current flowing back along the shield:

$$\hat{I}_s = \frac{j\omega L_{GS}}{R_{SH} + j\omega L_{SH}} \hat{I}_G$$

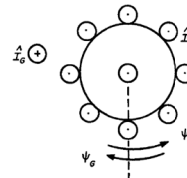
$I_s$  is then induced a secondary effect, the induced source in the receptor wire-ground plane loop.



$$R_{SH} = r_{SH} L$$

$$r_{SH} = \frac{1}{2\pi t_s r_s \sigma}$$

$r_s$  = shield interior radius  
 $t_s$  = shield thickness.



Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, Joh

## I. Shielding the Receptor (Cont.)

### B. Inductive Coupling (Cont.)

Consider the equivalent circuit for the receptor wire:

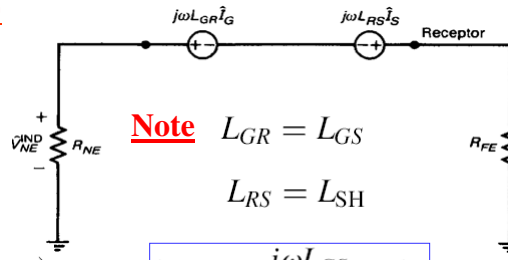
The near-end induced crosstalk voltage (due to sources) is

$$\hat{V}_{NE}^{IND} = \frac{R_{NE}}{R_{FE} + R_{NE}} j\omega (L_{GR} \hat{I}_G - L_{RS} \hat{I}_S) \text{ with } \hat{I}_S = \frac{j\omega L_{GS}}{R_{SH} + j\omega L_{SH}} \hat{I}_G$$

$$\hat{V}_{NE}^{IND} = \frac{R_{NE}}{R_{FE} + R_{NE}} \frac{j\omega R_{SH} L_{GR} + \omega^2 (L_{GS} L_{RS} - L_{GR} L_{SH})}{R_{SH} + j\omega L_{SH}} \hat{I}_G$$

where  $\hat{I}_G = \frac{1}{R_S + R_L} \hat{V}_S$ ,  $L_{SH} = l_{SH} L$  &  $R_{SH} = r_{SH} L$

$$\therefore \hat{V}_{NE}^{IND} = \frac{R_{NE}}{R_{FE} + R_{NE}} j\omega L_{GR} \hat{I}_G \left( \frac{R_{SH}}{R_{SH} + j\omega L_{SH}} \right) \text{ Effect of shield}$$



**Note**  $L_{GR} = L_{GS}$   
 $L_{RS} = L_{SH}$

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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## I. Shielding the Receptor (Cont.)

### B. Inductive Coupling (Cont.)

The inductive coupling contribution can be summarized as three cases:

- **Case I: The shield is not grounded at both ends ( $I_s=0$ ):**

$$\hat{V}_{NE}^{IND} = j\omega \left\{ \frac{R_{NE}}{R_{NE} + R_{FE}} \frac{L_{GR}}{R_S + R_L} \right\} \hat{V}_S$$

$$\hat{V}_{FE}^{IND} = j\omega \left\{ -\frac{R_{FE}}{R_{NE} + R_{FE}} \frac{L_{GR}}{R_S + R_L} \right\} \hat{V}_S$$

inductive coupling is not eliminated

- **Cases II & III: The shield is grounded at both ends:**

The result is the same as above but multiplied by a **shielding factor**:

$$SF = \frac{R_{SH}}{R_{SH} + j\omega L_{SH}} = \frac{1}{1 + j \frac{f}{f_{SH}}} \text{ where } f_{SH} = \frac{R_{SH}}{2\pi L_{SH}}$$

$R_{SH}$  and  $L_{SH}$  are the total resistance and self-inductance of the shield,

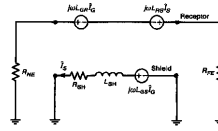
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## I. Shielding the Receptor (Cont.)

### B. Inductive Coupling (Cont.)

➡ For grounded shield at both ends



$$f_{SH} = \frac{R_{SH}}{2\pi L_{SH}}$$

➤ Case II: The shield is grounded at both ends and  $f < f_{SH}$ :

$$SF = \frac{1}{1 + j\frac{f}{f_{SH}}} \quad \Rightarrow \quad SF \cong 1 \text{ (slightly less than 1)}$$

which leads to:

$$\hat{V}_{NE}^{IND} = j\omega \left\{ \frac{R_{NE}}{R_{NE} + R_{FE}} \frac{L_{GR}}{R_S + R_L} \right\} \hat{V}_S$$

$$\hat{V}_{FE}^{IND} = j\omega \left\{ -\frac{R_{FE}}{R_{NE} + R_{FE}} \frac{L_{GR}}{R_S + R_L} \right\} \hat{V}_S$$

inductive coupling is not eliminated but slightly reduced

The generator current finds the lowest-impedance return path through the ground, and the flux from this current threads the entire receptor circuit.

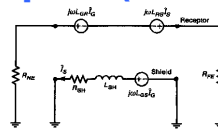
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## I. Shielding the Receptor (Cont.)

### B. Inductive Coupling (Cont.)

➡ For grounded shield at both ends



$$f_{SH} = \frac{R_{SH}}{2\pi L_{SH}}$$

➤ Case III: The shield is grounded at both ends and  $f > f_{SH}$ :

$$SF = \frac{1}{1 + j\frac{f}{f_{SH}}} \quad \Rightarrow \quad SF \cong -j\frac{f_{SH}}{f}$$

which leads to:

$$\hat{V}_{NE}^{IND} = \frac{R_{NE}}{R_{NE} + R_{FE}} \frac{L_{GR}}{R_S + R_L} \frac{R_{SH}}{L_{SH}} \hat{V}_S$$

$$\hat{V}_{FE}^{IND} = -\frac{R_{FE}}{R_{NE} + R_{FE}} \frac{L_{GR}}{R_S + R_L} \frac{R_{SH}}{L_{SH}} \hat{V}_S$$

The crosstalk is independent of frequency.

The generator current finds the lowest-impedance return path to be back along the shield instead of through the ground resulting in no additional magnetic flux threading the receptor circuit for increasing frequencies.

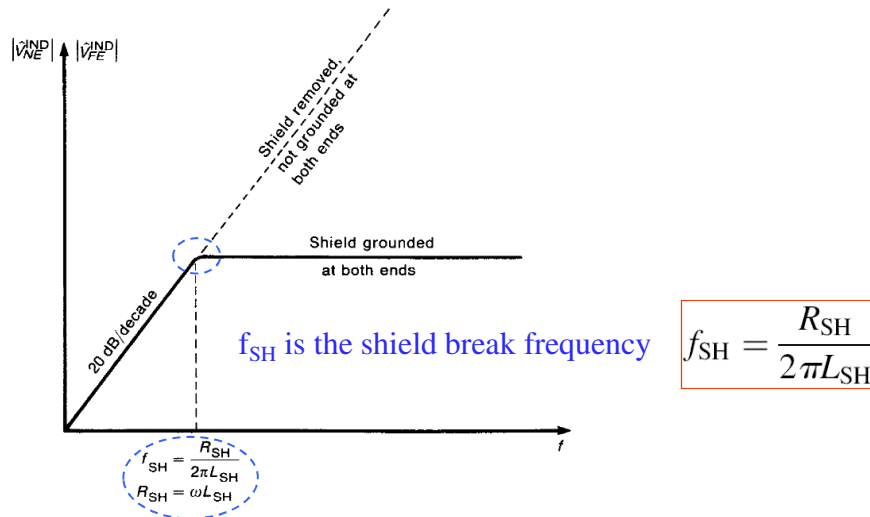
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## Shielding the Receptor

### B. Inductive Coupling (Cont.)

The effect of shield grounding on the inductive coupling to a shielded wire.

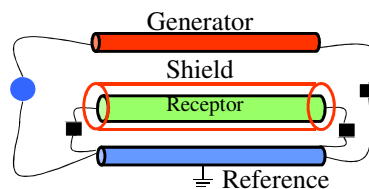


Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

## Shielding the Receptor

In summary, if the shield is grounded at at least one end,

- the capacitive coupling contribution is zero, and
- the inductive coupling is affected by the shield only if the shield is grounded at both ends and the frequency is greater than the break frequency, shield  $f > f_{SH}$



Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

**9.7.5** Consider the case of two wires above a ground plane shown in Fig. P9.4.4. The line has parameters of  $l_m = 2$  nH/m,  $c_m = 0.6$  pF/m,  $V_S(t) = 1 \cos \omega t$  V,  $f = 1$  MHz,  $\mathcal{L} = 2$  m,  $R_S = 0$ ,  $R_L = 50 \Omega$ ,  $R_{NE} = 100 \Omega$ , and  $R_{FE} = 200 \Omega$ . A shield is placed around the receptor wire, and is connected to the ground plane only at the near end. Determine the near-end crosstalk voltage. [ $0.1676 \cos(\omega t + 90^\circ)$  mV] By how much does the shield reduce the crosstalk? [12 dB]

Connection at one end,  $V_{NE}^{CAP} = 0$   $\hat{V}_{NE}^{IND} = j\omega \left\{ \frac{R_{NE}}{R_{NE} + R_{FE}} \frac{L_{GR}}{R_S + R_L} \right\} \hat{V}_S$

Without shielding:  $\frac{V_{NE}}{\hat{V}_S} = j\omega \left( \frac{R_{NE}}{R_{NE} + R_{FE}} \frac{L_m}{R_S + R_L} + \frac{R_{NE} R_{FE}}{R_{NE} + R_{FE}} \frac{R_L C_m}{R_S + R_L} \right)$

**9.7.6** The shield of Problem 9.7.5 is connected to the ground plane at both ends, and has a per-unit-length resistance of  $1 \Omega/m$  and per-unit-length self inductance of  $16 \mu\text{H}/m$ . Determine the near-end crosstalk voltage. [ $1.667 \cos(\omega t + 0^\circ)$   $\mu\text{V}$ ]

Connection at both ends, Calculate  $f$ ,  $\rightarrow f > f_{SH}$

$$\hat{V}_{NE}^{IND} = \frac{R_{NE}}{R_{NE} + R_{FE}} \frac{L_{GR}}{R_S + R_L} \frac{R_{SH}}{L_{SH}} \hat{V}_S$$

Source: P.R. Clayton: Introduction to Electromagnetic Compatibility, 2nd edition, 2006, John Wiley & Sons.

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