

# Antenna & Feedline Selection

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**Control Microsystems White Paper  
November 2010**

**This white paper gives the reader an understanding of issues affecting the selection of antennas and feedline. It describes the complete signal path from transmitter to receiver and includes hardware specifications, required calculations and path-loss issues.**

**Through an improved understanding of the subject, the reader will more effectively and confidently be able to design, install and maintain a reliable wireless communication system.**

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Date: November 4, 2010**

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# 1. System Hardware Selection

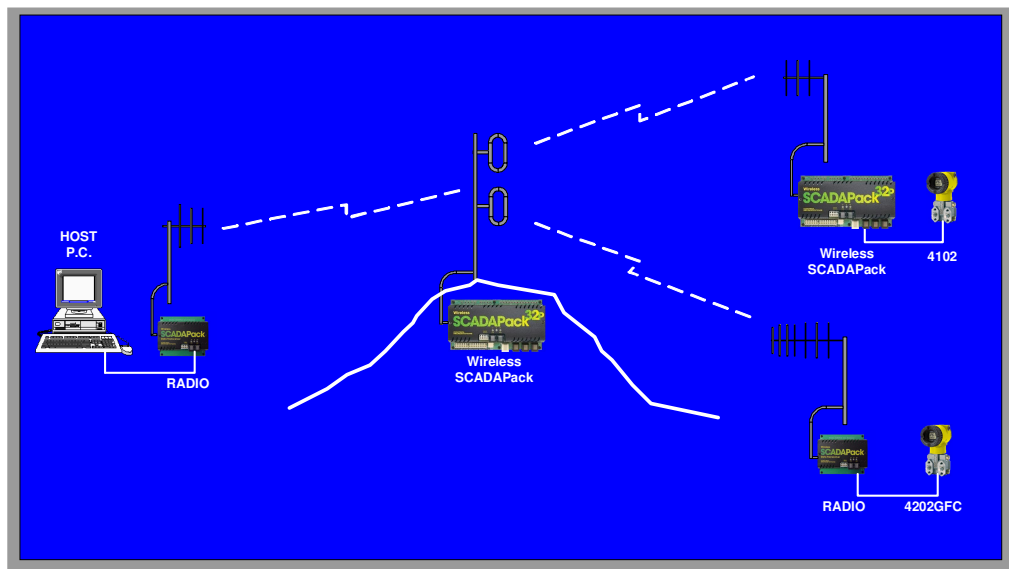
## 1.1. Overview

The selection of antennas, feedline and other hardware for data radio systems requires an understanding of the hardware specifications (as quoted by the equipment manufacturer) and of the end-to-end signal path. This understanding will allow informed decisions for improving overall system reliability.

Aspects of the signal path to be considered include the radio transmitter, feedline and connectors, antenna parameters (such as gain, beamwidth and polarization), the path between antennas, and the receiver.

In actual radio system installations, hills, trees, buildings, and even rain clouds can obstruct the signal path between radio antennas. These obstructions can cause signal losses, signal refraction and reflection, and must be taken into account when minimizing fading effects.

Once the various aspects of the path have been considered, the total path loss can be calculated. This will give the engineer the information needed to decide whether changes need to be made, and where these changes will be most effective.



**Figure 1 - Typical Radio Telemetry System**

## 1.2. Signal Path

To make decisions about the hardware needed for a particular radio telemetry project, the following components of the end-to-end signal path must be considered:

- Radio Transmit Power
- Feedline and Connectors
  - DC and AC Losses
  - Connectors and Other Devices
- Antenna Considerations
  - Common Types
  - Gain
  - Beamwidth
  - Bandwidth
  - Polarization
  - Mechanical Considerations
- Path Losses
- Receiver Sensitivity

### 1.2.1. Radio Transmit Power

A typical 900 MHz spread spectrum radio transmits a 1 watt signal, while a licensed 400 MHz UHF radio transmits a 5 watt (approx.) signal. On a licensed system the user can apply for greater output power (e.g. 25 to 50 watts). However this is not commonly done due to possible interference issues with other nearby radio systems. Older host radios typically function at 25 watts, as they have often been converted from voice repeaters.

#### Summary of common transmitter output values

Radio Type	Power Output	dBm Equivalent
Spread Spectrum	1 W	+30 dBm
UHF Licensed	5 W	+37 dBm
Voice Repeater	25 W	+44 dBm

## 1.2.2. Feedline and Connectors

- **DC and AC Losses**

The feedline, commonly called coax (coaxial cable) or hardline, will cause power loss due to DC resistance and AC impedance characteristics. These losses increase with the cable's length. This is unavoidable, as with any conductor, but can be minimized. Feedlines of greater diameter, or with varying types of dielectric (insulation between inner and outer conductor), can be used. They are, however, more expensive and difficult to install.

Feedline loss goes up as the frequency used goes up. Data communication systems typically use frequencies in the 400 MHz licensed band, and the 900 MHz and 2.4 GHz license-free bands. A cable that is suitable for use at 400 MHz may be totally unsuitable at 2.4 GHz. Similarly, a given cable may be fine for a 10 foot run but be too "lossy" for a 50 foot run.

- **Connectors and Other Devices**

Connectors and other devices such as surge or lightning arrestors will also cause signal loss. This is due to a combination of the increased resistance of the connectors and the impedance mismatch between one cable/connector and the next. All hardware for data radio is designed for a 50-ohm impedance, but minor design variations can cause losses.

**The following guide demonstrates the effects of increasing frequency, cable type and cable diameter on losses in coaxial cable.**

**Communications Coax Selection Guide**

Attenuation ( dB per 100 feet ; +25C )

Frequency / Size	2 1/4" LDF	1 5/8" LDF	1 1/4" LDF	LMR-1700	7/8" LDF	LMR-1200	LMR-900	1/2" LDF	LMR-600	LMR-500	1/2" SuperFlex	3/8" LDF	LMR-400	3/8" SuperFlex	9913	ULTRA-LINK™	RG213/RG214
30 MHz	0.096*	0.120	0.147	0.149	0.197	0.209	0.288	0.369	0.421	0.54	0.561	0.567	0.7	0.654	0.8	0.7	1.2
50 MHz	0.125*	0.156	0.191	0.195	0.257	0.272	0.374	0.479	0.547	0.70	0.730	0.736	0.9	0.848	0.9	--	1.6
150 MHz	0.227*	0.280	0.340	0.347	0.458	0.481	0.658	0.845	0.964	1.22	1.29	1.30	1.5	1.49	1.6	1.5	2.8
220 MHz	0.281*	0.345*	0.416*	0.427	0.560*	0.589	0.803	1.05*	1.18	1.49	1.58*	1.59*	1.8	1.82*	--	--	3.5
450 MHz	0.422	0.515	0.617	0.632	0.834	0.864	1.17	1.51	1.72	2.17	2.32	2.30	2.7	2.66	2.8	2.7	5.2
700 MHz	--	--	--	0.809	--	1.10	1.48	--	2.18	2.77	--	--	3.42	--	--	--	--
900 MHz	0.641*	0.767*	0.912*	0.936	1.23*	1.27	1.70	2.21*	2.50	3.13	3.41*	3.36*	3.9	3.86*	4.2	4.19	8.0
1,500 MHz	0.879*	1.050	1.22	1.26	1.66	1.69	2.24	2.93	3.31	4.13	4.57	4.43	5.1	5.12	5.6	--	--
2,000 MHz	1.058*	1.250	1.45	1.50	1.97	1.99	2.63	3.45	3.90	4.84	5.41	5.21	6.0	6.01	6.7	--	--
2,500 MHz	--	1.440	1.68*	1.71	2.27*	2.26	2.98	3.91*	4.42	5.48	6.17*	5.91*	6.8	6.84*	--	6.8*	--
5,800 MHz	--	--	--	--	--	--	4.90	--	7.30	8.90	--	--	10.8	--	--	--	--

Attenuation at Any Frequency = [ k1 x  $\sqrt{f}$  (Fmhz) ] + [ k2 x Fmhz ] or use Performance Calculator at [www.timesmicrowave.com](http://www.timesmicrowave.com)

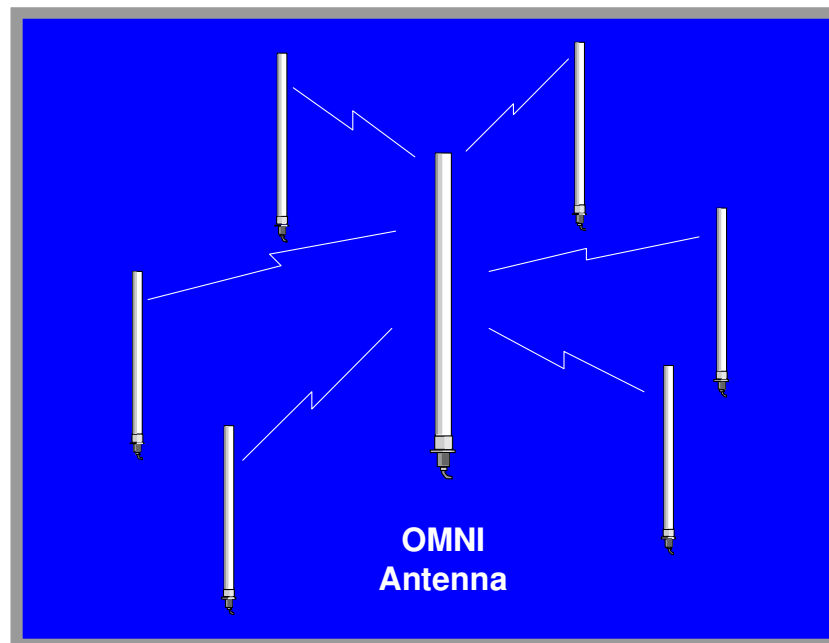
\* Courtesy of Times Microwave <http://www.timesmicrowave.com>

### 1.2.3. Antenna Considerations

Many antenna models exist, and the user must understand the basic differences in order to choose the correct type.

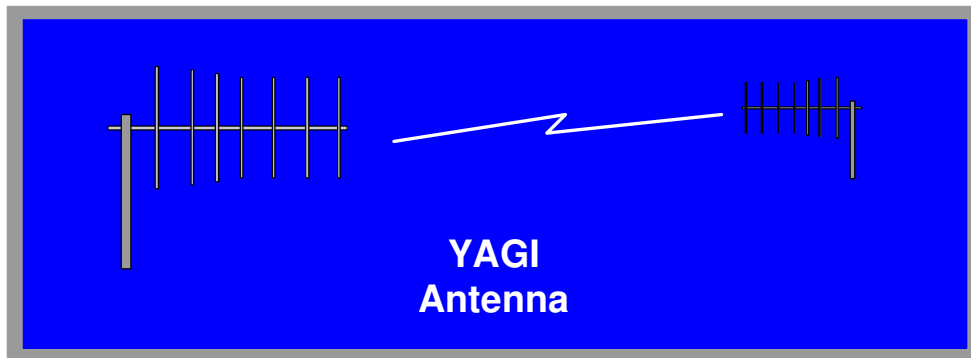
- **Common Antenna Types**

At a location (such as a repeater or host), which needs to communicate with several other sites scattered in various directions, an omni-directional, or **Omni**, antenna is chosen. This type has equal coverage in all directions, or may have an elliptical pattern that favours one direction somewhat. Normally an Omni antenna looks just like a pole, though some variants will have several loops (dipoles) hanging off one side, and is mounted vertically.



**Figure 2- Omni Antenna**

At a site that will only be communicating with one other site, or with several sites, all in the same direction, a **Yagi** antenna is typically chosen. The antenna is named after one of two Japanese scientists who developed the design. The Yagi antenna looks somewhat like rooftop TV antennas. It includes a horizontal boom and several elements, typically welded onto the boom.



**Figure 3 - Yagi Antenna**

A less common but important type of antenna is the **Corner Reflector**. This antenna is heavier and more complex than a Yagi antenna, but provides greater rejection of unwanted signals from the back and sides.

- **Gain**

Gain is considered to be an improvement in the level of an RF signal, typically measured in dB. An antenna will typically be of a design that provides some amount of gain, except for situations where the transmitter and receiver are very close together. For a vertical antenna, the taller it is (compared to other antennas in its frequency range), or the more loops it contains, the more gain it usually has. For a directional antenna, more elements typically means more gain.

An antenna's gain must have a reference point. For SCADA type antennas the usual reference is a simple dipole (1 element) antenna. A dipole antenna has 0 dBd gain. (the second d in dBd stands for dipole) A typical 7 element yagi antenna has about 10 dBd gain.

Another reference point sometimes used is dBi. In this case the antenna's gain is compared to a theoretical isotropic antenna. (radiates like the sun, perfectly in all directions) dBi tends to be used more at 2.4 GHz and above. Using a dBi reference point always makes an antenna appear 2.1 dB better than using a dBd reference. A dipole focuses the signal so most of it radiates perpendicular to the antenna.

Some antenna manufacturers will try to fool their customer by specifying dBi numbers, but instead just stating eg "10 dB gain." Such an antenna would actually have 7.9 dBd gain. However, an antenna whose gain is specified as eg 10 dBd would be equivalent to 12.1 dBi.

- **Beamwidth**

An antenna with higher gain typically has a narrow beam, somewhat like that of a flashlight. The signal will spread out both horizontally and vertically as it leaves the antenna. This is specified as horizontal & vertical beamwidth, measured in degrees. A typical 7-element Yagi might have about 50 degrees beamwidth. This is measured at points to either side of center where the signal drops off by 3 dB. A narrow beamwidth can be useful to reject unwanted signals from another system, while a wide beamwidth will allow communication with multiple sites some distance apart.

A high gain omni antenna will typically have a narrower vertical beamwidth, eg more like a pancake than a donut. This can be a problem if any remote sites are nearby yet significantly below the omni antenna.

- **Bandwidth**

Each antenna will have a stated bandwidth. This is the maximum useable range of radio frequencies. If the radio at a given site may need to move from one frequency to another (during an upgrade or reorganization of the network) then an antenna with a broader bandwidth may be needed. High gain antennas typically have narrower bandwidth.

- **Polarization**

All antennas within a given system must use the same antenna polarization. This means that each antenna must have all its elements oriented the same way, either vertically, or horizontally, as other antennas in the system. Due to the nature of electro-magnetic fields generated by antennas, one antenna, oriented incorrectly, may suffer as much as a 20 dB loss in signal. Data radio systems typically use vertical polarization.

- **Mechanical Considerations**

Any antenna will have various mechanical factors to consider. How the antenna will be supported must be taken into account – on a tower (self-supporting or guyed), on a mast, or perhaps on a tripod? Depending on the model it may be quite heavy, and its wind loading may become a factor. The maximum wind velocity in the area (combined with the possibility of icing in winter) must be noted; both when purchasing an antenna intended to survive inclement weather, and to ensure the support structure will survive. When a tower is purchased the combination of required height and wind loading will greatly affect the cost.

#### 1.2.4. Path Losses

Once the RF signal leaves the transmit antenna, it must travel a certain distance through the atmosphere before it reaches the receive antenna. Many factors will affect the signal through this distance.

The distance between the antenna sites has the greatest effect on losses. Radio signals follow the inverse-square law. If a signal is measured at 1 km (for example) from the transmitter, and then again at 2 km, the signal will be  $\frac{1}{4}$  as strong at 2 km as at 1 km. (6 dB weaker) Also, if the sites are far enough apart then the curvature of the Earth itself will prevent the sites from hearing each other.

Any physical obstacle the signal must travel through will affect the received signal strength. This includes rain, snow, trees (wet conditions cause more attenuation than dry), buildings and so on. Trees or other obstructions near the site, or the Earth's curvature, will produce conditions requiring a mast or tower. Metal buildings, hills and lakes may cause harmful reflections.

A radio signal will diffract around obstacles such as hills or buildings, but this does cause losses. Also, the higher the frequency used the less the signal will diffract, or bend. For example a 2.4 GHz signal diffracts very poorly compared to a 450 MHz signal. Diffraction is a key component of many paths used in SCADA systems, where paths are often obstructed.

Another problem that can occur regularly along a path is signal fading. The signal can decrease over a matter of minutes, or perhaps hours. The depth of the fade will depend on a variety of factors, such as weather. It may reach 20 dB or more, which must be taken into account if the path is to remain reliable. This is more of a concern at higher frequencies.

#### 1.2.5. Receiver Sensitivity

A data radio consists of both a transmitter and a receiver. It may also include a modem, as in the Trio unlicensed radios. The receiver is limited in terms of how weak a signal it can successfully detect by such factors as external atmospheric and internal circuit noise. This is called receiver sensitivity. In order to allow high-speed data throughput (low bit error rates), the received signal must meet certain standards.

Taking the Trio K Series (Serial) radio as an example:

- -108 dBm signal gives a bit error rate at 32 kbps of  $1 \times 10^{-6}$
- -102 dBm signal gives a bit error rate at 256 kbps of  $1 \times 10^{-6}$

A bit error rate of  $10^{-6}$  means that only one data bit in 1,000,000 will be incorrect. This is a desirable target to aim for, and should not be difficult for the system protocol to correct.

**Note:** See Section 2 for a tutorial on using the decibel.

### 1.3. Signal Path Results

All of the parameters discussed in section 1.2 add or subtract from the original transmitted signal. The resulting signal must still be strong enough to allow the receiver to decode data.

#### 1.3.1. Fade Margin

In order for a radio path to be reliable despite changing environmental conditions or maintenance issues, the received signal strength must normally remain well above the radio's specified receiver sensitivity. The difference between the actual received signal level and the radio's receiver sensitivity is called Fade Margin. For typical SCADA or Telemetry applications a 20 dB fade margin is considered good. 15 dB may be allowable on a low priority path, while 30 dB or more may be required on critical paths.

#### 1.3.2. Path Loss Calculations

Here is an example of a complete path:

Transmit power:	+ 30 dBm	(1 watt)
Cable & connector loss:	- 3 dB	
Transmit antenna gain:	+ 12 dBi	(same as 10 dBd)
Path losses:	-136 dB	
Receive antenna gain:	+ 12 dBi	
Cable & connector loss:	<u>- 3 dB</u>	
Received signal level:	- 88 dBm	
Sensitivity ( $10^{-6}$ BER):	<u>-108 dBm</u>	
	20 dB Fade Margin	

**Note:** In this example, if the path or cable/connector losses were greater, then higher gain antennas would be needed to ensure a 20 dB fade margin. Alternately, increasing one or both tower heights might reduce the path losses due to trees or other effects.

### **1.3.3. Path Studies**

For a system with sites more than about 2 km apart, or where significant obstacles exist, a path study should be done. It may be requested that Control Microsystems perform this study. A path study request form is available online at: <http://www.controlmicrosystems.com/resources-2/software-downloads/radio-path-study-requests/> This document must be filled out as fully and accurately as possible, then must be emailed to [pathstudy@controlmicrosystems.com](mailto:pathstudy@controlmicrosystems.com).

A field survey is also often desirable, for example to get exact site coordinates, to note details about obstacles, and possibly also attempt to set up several test paths. This will demand the service of an independent contractor equipped with proper test equipment.

## **1.4. Conclusion**

To make decisions about the hardware needed for a project, the end-to-end signal path must be considered. This includes the transmitting radio's power output, feedline and connectors, antennas, the path between antennas, and the receiving radio's sensitivity.

Factors that affect feedline performance include the frequency chosen, cable length and cable diameter. When choosing antennas such features as gain, beamwidth, bandwidth, and polarization must be taken into account. The antenna's height above ground is also of great importance.

Any medium that the signal must pass through will cause either a gain or a loss in signal strength. The antennas chosen will typically provide some degree of signal gain. The feedline, connectors, distance between antennas, weather, buildings & trees, will all cause signal losses.

The transmitter output can be converted to dBm as a starting reference point. All gains and losses in the signal path are then added to or subtracted from this value. The resulting level must, at minimum, be greater than the receiver's sensitivity by an amount called the fade margin. A higher receive signal strength will typically provide a reduced bit error rate.

## 2. Calculating and Estimating Decibel Values

The unit for signal strength calculations is the decibel (dB). It is typically related to a standard level of 1 milliwatt (1 mW) of RF (radio frequency) power into a 50 ohm load. This is written as:

$$1 \text{ mW} = 0 \text{ dBm} \quad (\text{dB relative to 1 mW})$$

Anything the RF energy must pass through will cause either a gain or loss, which will be measured in dB (decibels).

An equation is used to convert between power and dBm. It's not necessary to know it for rough calculations but here it is:

$$\text{dBm} = 10 \log ( P / P_{ref} ) \quad (\text{where } P_{ref} \text{ is typically 1 mW})$$

Example: A UHF radio puts out 5 watts. Convert to dBm.

$$\begin{aligned} \text{dBm} &= 10 \log ( 5 \text{ watts} / 0.001 \text{ watt} ) \\ &= 10 \log ( 5000 ) \\ &= 10 \times 3.7 \\ &= +37 \text{ dBm} \quad (37 \text{ dB greater than 1 mW}) \end{aligned}$$

Two simple **rules of thumb** help to avoid using the above equation. Remembering these allows some quick field estimates to be made.

- Doubling or halving the power causes a +3 dB or -3 dB change.
- Doubling or halving the distance between two sites causes a -6 dB or + 6 dB change. (the inverse square law - discussed above)
- Changing the power by a factor of 10 causes a +10 dB or -10 dB change.

Using these rules of thumb, that 5-watt UHF radio calculation can be done simply this way:

Example:	1 mW to 10 mW	+10 dB	= +10 dBm
	10 mW to 100 mW	+10 dB	= +20 dBm
	100 mW to 1 watt	+10 dB	= +30 dBm
	1 watt to 10 watts	+10 dB	= +40 dBm
	10 watts to 5 watts	-3 dB	= <b>+37 dBm</b>

**Note:** Any weak signal will be displayed as a negative number. (E.g. -85 dBm) Received signals are typically in the -50 to -100 dBm range.

# 3. Glossary

<b>Attenuation:</b>	Amount of signal loss, measured in decibels.
<b>Bandwidth:</b>	Maximum useable range of radio frequencies.
<b>Beamwidth:</b>	Amount by which the signal spreads out from a straight line, measured in degrees, at the -3dB points.
<b>Corner Reflector:</b>	A type of directional antenna that provides a certain amount of rejection of unwanted signals from the back and sides
<b>Decibel (dB):</b>	Unit of reference. 0 dBm equals 1 milliwatt of power into a 50 ohm load.
<b>Diffraction:</b>	Change in the direction and strength of a radio wave as it passes by an obstacle or through an aperture.
<b>Fading:</b>	Temporary loss of signal strength due to environmental changes eg weather.
<b>Feedline:</b>	Coaxial cable, carries the signal between radio and antenna.
<b>Frequency:</b>	Part of the radio spectrum being used, measured in Hertz, or cycles per second.
<b>Gain:</b>	Improvement in the level of an RF signal.
<b>GHz:</b>	Abbreviation of Gigahertz. A frequency of one billion hertz (cycles per second).
<b>Host:</b>	Master station, in control of a communication link.
<b>Impedance:</b>	Opposition to flow of alternating current. (eg. radio signals)
<b>Lossy:</b>	Having a degree of attenuation, or reduction in signal.
<b>MHz:</b>	Abbreviation of Megahertz. A frequency of one million hertz (cycles per second).
<b>Omni:</b>	Abbreviation of Omni-directional. Radiating equally in all directions.
<b>Path:</b>	The route taken by a signal between transmitter and receiver.
<b>Polarization:</b>	Orientation of the antenna elements in a radio system.
<b>Repeater:</b>	A system which rebroadcasts any signal it detects.
<b>Sensitivity:</b>	The ability of a receiver to detect, or decode, a signal.

**Spread Spectrum:** A type of radio that hops between multiple frequencies at a rapid rate in order to minimize interference from other systems or noise sources.

**UHF:** Abbreviation of Ultra-High Frequency. Between 300 and 3000 MHz.

**Yagi:** A type of directional antenna, with multiple elements. Technically known as a Yagi-Uda, after its designers.

# 4. More Information

## 4.1. Links to relevant manufacturer sites:

### 4.1.1. Antennas:

<http://www.pctel.com>  
<http://www.sinctech.com>  
<http://www.lairdtech.com>

### 4.1.2. Cables & Connectors:

<http://www.timesmicrowave.com>  
<http://www.andrew.com>

### 4.1.3. Surge Arrestors:

<http://www.polyphaser.com>

### 4.1.4. Towers:

<http://www.trylon.com/home.asp>

### 4.1.5. Radios:

<http://www.triodatacom.com>  
<http://www.freewave.com>  
<http://www.microwavedata.com>

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