**HX5 The Next Generation Ultrasonic Positioning**

Hexamite is proud to present the Next Generation (hx5) in ultrasonic positioning. The hx5 utilizes modulated signal exchange to extract precision position timing. The modular construction facilitates easy installation, maintenance and expansion. The hx5 is cost effective with high noise immunity and high accuracy. Using multiple networks an object can be positioned to within 2 centimeters anywhere in an area of many square kilometers. There is no fixed limit of coverage; about 0.5 square kilometer can be covered to a reasonable accuracy using a single network. And of course the Internet can be harnessed to locate anything globally to within 2 centimeters. As many as 20 positions, can be registered by each receiver per second. In a medium system counting hundreds of transmitters and receivers, there can be thousands of positions registered each second.

**Application**

- Machinery Position Feedback
- Robotics Guidance and Tracking
- High Security Object Tracking
- High Security Object Guidance


Figure 1. Hexamite Ultrasonic Position Transmitters/Tags

**Features**

- Area Coverage up to 495000 $m^2$ per Network
- Up to 20 Position Updates per Second by each Monitor
- High Environmental Noise Immunity
- Absolute Accuracy over full range +/- 9mm
- Easy installation, maintenance and expansion.


Figure 2. Hexamite Network Controller HX5C1 to the left. Ultrasonic Position Receivers/Monitors HX5M1 to the right

**Ultrasonic Positioning**

Ultrasound remains the lowest cost positioning option with respect to accuracy, repeatability and positioning resolution. The line of sight drawback for ultrasonic positioning may actually be an advantage for some applications. Ultrasound is completely confined to the area in which it operates. This means that neither can it effect operation outside it's boundaries, nor can anything outside the boundaries effect it. Simply, operation in one room can be completely separated from operation in nearby rooms. This is also true to an extent for separators in a large hall.

Unlike radio tracking ultrasound cannot be jammed using an unsophisticated radio transmitter located outside or inside the complex. Multi-path errors are made irrelevant by ensuring a line of sight; the operation is secure and private. Sunlight harmful to infrared systems will not affect ultrasound. With reasonable precautions ultrasound can be used outdoors as well as indoors.

**Tracking Vs Guidance**

Tracking refers to a situation where a central device, for example a computer, monitors the position of satellite objects or moving objects relative to fixed points. In a tracking system, the moving objects are not aware of their position. If in a tracking situation autonomous operation is also required; the positions can be relayed or broadcasted by remote communication from the central device, to the moving object.

Guidance (inverse tracking) refers to a situation where moving objects (autonomous) calculate their positions relative to satellite objects. This entails setting the transmitters up in fixed locations and using the receivers to guide the autonomous object. Guidance can also be accomplished by tracking the moving objects using a central device, and broadcasting the positions of all transmitters.

**Basic Components of the Positioning System**

Guidance or a tracking system (or combination of both) can be realized using two fundamental components. These are signal transmitters (tags) and signal receivers (monitors). Auxiliary devices like computers and network controllers, can be used to calculate the position of the tags utilizing information from the monitors.

The HX5 denotes series of signal transmitters and receivers for the construction of guidance, or tracking systems. For a tracking system the receivers can register signals from up to 1024 tags, (if a higher number is required contact hexamite). A guidance system of 1024 reference points with unlimited number of autonomous monitors can be created using the HX5 components.

**The Basic System**

The following lists the basics needed for the construction of a tracking or guidance system using the HX5 components

**Hardware Needed for a Complete Ultrasonic Tracking System**

| | |
|---|---|
| Receivers/Monitors HX5M | Quantity depends on the area covered |
| Transmitters/Tags HX5T | Quantity depends on the number objects tracked |
| Network Controller HX5C | One controller per network |
| Personal Computer | One PC per network |
| Regulated DC power supply | Minimum one supply per network |

*For a network containing more than 128 receivers, a HX5R repeater will be required.*

**Materials needed for network wiring**

4 conductor telephone cable
FCC Modular Plugs 6/4 RJ11

**Software for reading (real time) and storing data**

The following programs come with the Hx5 devices.

**Hx5Data.exe**

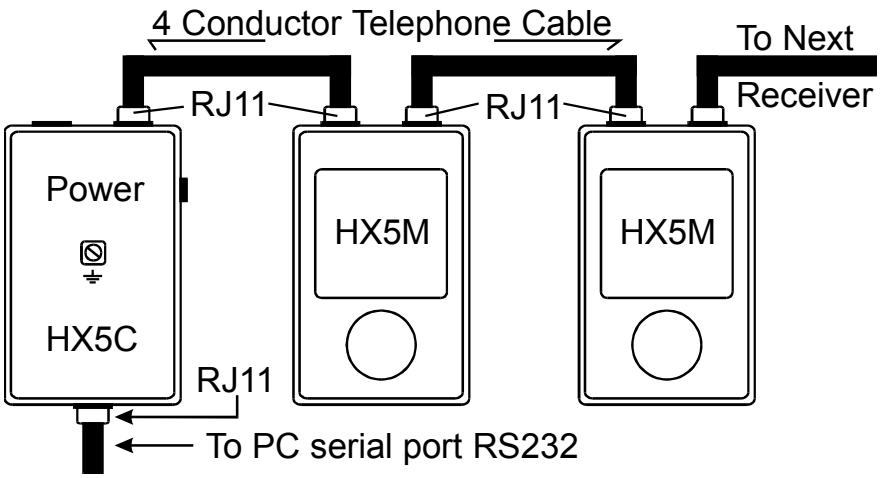
This program reads data from the HX5NC (network controller). It stores the data on a file name monData.hxm.

**XYZ.EXE:** Reads data from the HX5 network via the serial port, and converts the data to tag Id, 3D coordinates and time. It also converts the file collected by the hx5data program "monData.hxm" to tag ID, 3D position and time. This data is stored on a file named by the time and date the data was acquired. The user can tap into all data as it is being created by the xyz.exe program; for real time monitoring. This is done using DDE (Dynamic Data Exchange) see (DDE example) below.

**LAYOUT.EXE:** allows the user to set up the positioning network (location of receivers/monitors) visually on a floor plan or a background picture (gif image). 3d positioning files created by the xyz program can be displayed on the image. The user can back step through the position timeline on the background image and replay any sequence. The positions of the tags can also be displayed in real time on the background image as the data it is being sampled.

**Receiver/Monitor Setup**

The HX5M can be connected to a network of devices utilizing FCC RJ11 style port. The RJ11 socket can be found on most domestic telephones. It is the socket, which connects the telephone to the wall fixture. Each HX5M has two RJ11 sockets, which are identical. The communications and power to the HX5M is supplied via the RJ11 port.




The total cable length should not exceed 10 miles or 16 kilometers. All receivers have a direction diode on the input, reverse polarization does not harm the units.

**The Network Controller HX5C**

HX5C controls the network and the communications with the PC, it should be located within 2 meters of the PC. The program xyz.exe reads the data from the HX5C and calculates the position of the transmitters detected. The power points on the HX5C are connected to the network power lines via diode, and can serve to supply power to the whole network. Be aware that telephone lines carry limited amperes and there is a voltage drop in direct proportions to the wire length. In case of long lines, and high number of receivers it may be necessary to use local power for a far away cluster of receivers.

Note that it may be necessary to ground the power supply used to supply the network with power. Some switching power supplies used for laptops can cause excessive line noise.

**Controlling The System Update Rate**

It takes each tag 13mS to transmit it's identification and localization signal. The monitor needs 10mS to analyze and store signal data. In random mode the tags high rate, limits the update rate to about 25 distance readings per second. Two random mode tags in range of one another updating 25 times/second; will have high tendencies to overrun. The tag closest to the sensor is likely to override the tag further away. The monitors can be set for a maximum update rate of 40 times / second. This means that each monitor on the network transmits the contents of it's memory at this rate. Due to the communications bottleneck a large system running at this rate will have to be split into many smaller systems running on a network PCs. Each HX5 controller running at 125000 baud can handle 38 tag encounters at an update rate of 40 tags/second. The tag encounter is the product (number of tags times number of monitors).

**The Power Supply**

Voltage levels on the supply lines to the receivers should not be lower than 7 V and not higher than 16 Volts. In regards to the lower level, the voltage should never go below 7V dc, a microsecond spike beneath the level can disrupt the operation. Therefore regulated supplies should be favored.

**The Personal Computer**

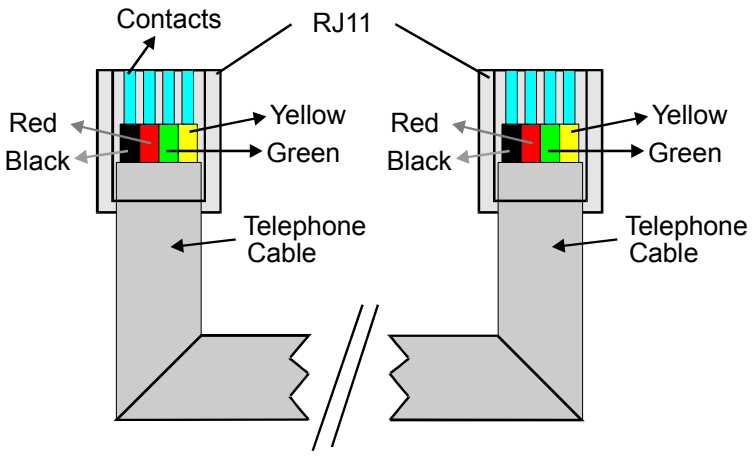
The PC calculates the position of each transmitter based on the data from the HX5C. In the case of over 1000 transmitters being detected by several hundred receivers, a high speed PC should be used as a dedicated server. Most PCs will suffice for real time monitoring of a few transmitters and receivers.

**The Transmitter**

The transmitter transmits localization signal followed by it's identification. HX5T1 is limited to 1024 unique identification. Hexamite can deliver custom systems with unique identifications in the millions.

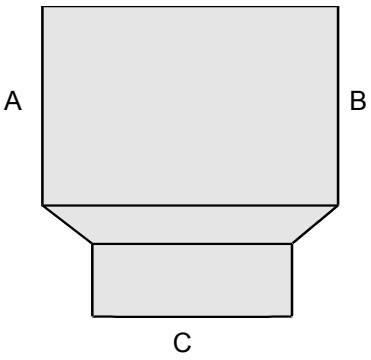
**FCC RJ11 and telephone cables**

The figure on the right shows how the rj11 needs to be attached to the cable. It is important that the colors match when the cable ends are held side by side. Inexpensive tools are available to help join the RJ11 to the telephone cable. It does not damage the monitors if they are connected via inverted cable. But it could block out the network until removed and corrected.




**Using T connectors**

T-Connectors are generally available at hardware stores selling telephone cables and accessories. The T connector joins 3 separate telephone cables, and it has 3 RJ11 sockets A, B and C. Some T connectors have the C input inverted. In this case the cable connected via the C input must be inverted too. This means that the colors as shown in the figure a3 should not match, the RJ11 should be joined to the cable rotated 180 degrees.

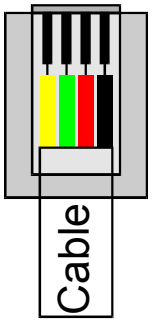



Long Line Considerations

If the network becomes kilometers long, a twisted pair should be used to carry the communications signal and the receivers should be supplied with power locally. The network 4 conductors are

HX5 Network

The illustration on the right shows a RJ11 plug, the yellow wire is the supply power and the black line is the return (ground). The red and the green conduct the communications signal. In the case of a long line application with many power supplies only two lines i.e. the Green and the Red should be connected throughout the network. The common mode voltage on the communication wires is +/- 7V.




Local Power

Long line network may not be suited to carry the power to devices far away, and local power must be used. In this case the outmost wires black and yellow should not be connected in the RJ11 plug. For a long line situation it may be best to use only the data lines for long distance data transmission, and use local power for the monitors.

HX5 System Specification

| | |
|---|---|
| Positioning Timing Resolution Per Monitor | 0.03 mm |
| Open Field Absolute accuracy over full range | 9mm |
| Position Repeatability | 0.1mm |
| Maximum Position Update Rate | 20 (Positions/Sec)/Monitor |
| Maximum number of Monitors per Network | 55000 |

**Position Resolution**

This is the timing resolution; meaning theoretically if the position changes by 0.03mm a change in distance value should be noted. This resolution can be approached in a case of a slow moving object, where there is time for hefty averaging.

**Open Field Absolute Accuracy**

Position is nowhere off by more than 9mm over the full range, given that the air medium remains the same in terms of speed of sound and no objects obscure the wave.

**Position Repeatability**

Given constant conditions of the air medium, if the transmitter is moved into a previously held position, the new reading will not deviate more than 0.1mm from the original reading on the average. This makes calibration for high absolute accuracy possible.

**Maximum Position Update Rate**

Each monitor can register 20 positions/second from either one tag or multiple tags.. The total will never exceed 20 positions/second

**Monitors per Network**

The maximum number of monitors per network is 55000, this means that if there is one monitor for every 9 square meters 9 x 55000 square meters can be covered with a single network. If more coverage is needed more networks can be added.

**Monitor Noise Immunity**

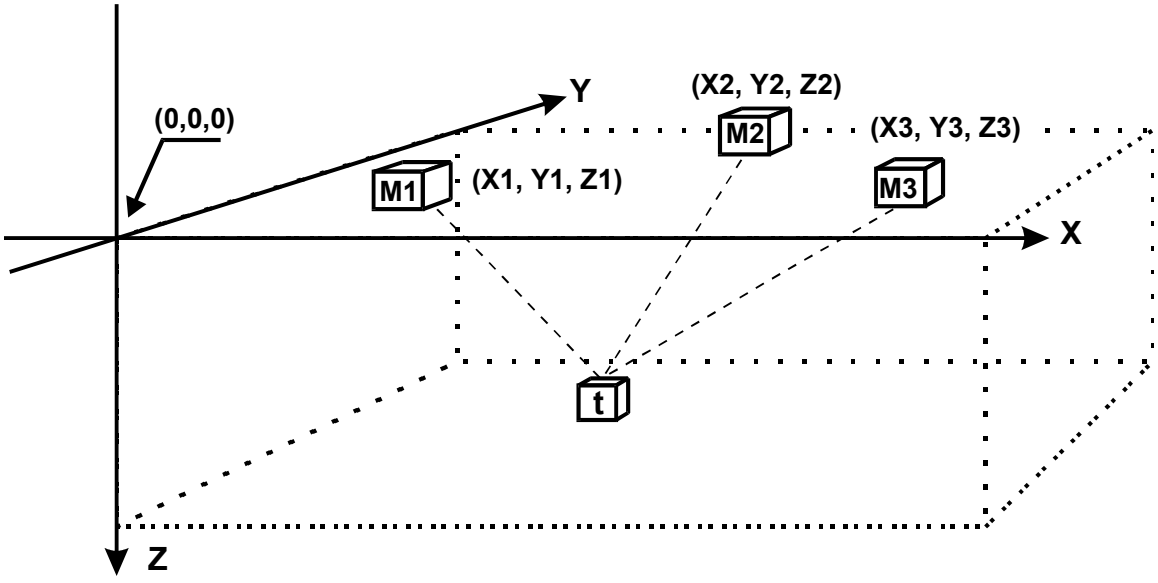
The HX5 transmission is frequency modulated. to block or upset the transmission a signal noise must exist in the 40khz +/- 1Khz band. If the volume of this signal is 5db lower than the HX5 transmission at the receiver, no distance distortion is measured. In other words the noise must overwhelm the transmission.

**The XYZ program**

The xyz.exe and layout.exe come with a HX5 positioning system see (The basic system section)

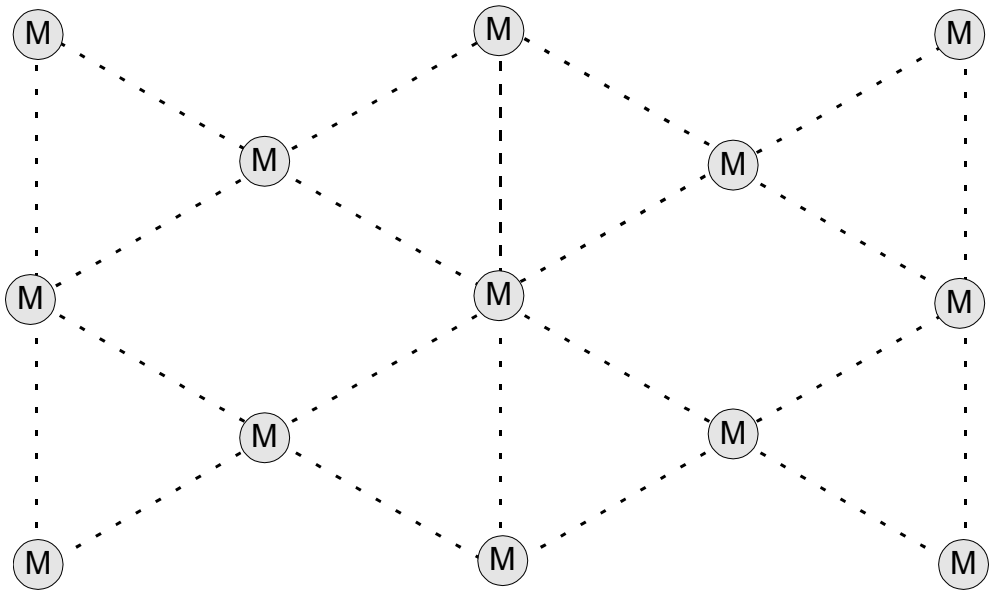
The XYZ program requires that the (x,y,z) coordinates be specified for each monitors on the network. These coordinates can be entered into a text file (layout.hxm) either manually or on a floor plan (background image) using the layout program. The xyz program reads this file and calculates the position of the tags based on these coordinates, relative to a single origin (0,0,0), placed at the users convenience. The tag coordinates and time of encounter are stored in directory [xyz Data]; on a file with a name given by time and data . Other program applications have access to the xyz data stream via DDE (dynamic data exchange).

An auxiliary program layout.exe helps set up the monitors visually. A floor plan or a picture in GIF format can be imported into the program as background. The program allows the picture to be scaled, and the user can zoom the picture in and out and move it around on the screen. The origin can be placed anywhere on the background picture and the monitors placed visually (graphically) according to measurement on the background. Layout.exe has features that allow the files created by the xyz program to be displayed on the background image. The positions of all the tags can be displayed on a timeline. I.e. these can be back stepped and forwarded at high and slow speeds and the positions of the tags can be frozen in time. The image below suggests how the monitors can be set up for example in a room where the 0 (xy) plane is the ceiling.



**Wide Area Coverage**

The illustration below suggests how a large area can be covered using monitors. Any formation can be chosen, but a honeycomb formation will provide one of the best coverage per unit cost. In the following the D distances between monitors are everywhere the same. The monitors form 60-degree triangles. Depending on the density of the network, many monitors may contribute to the positioning of a given tag. The higher then number of monitors that detect the tag, the more accurate and stable will be the positioning.

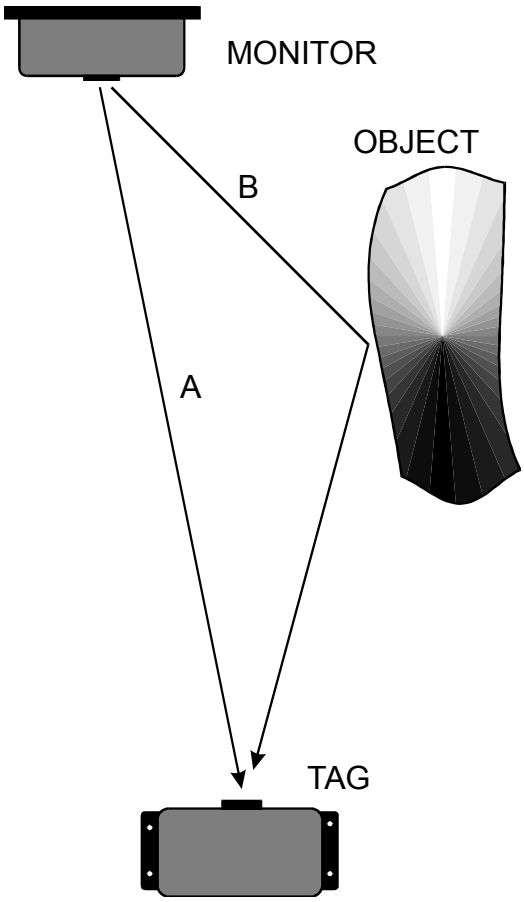



**Setting up for Z evaluation**

The HX5 operates on equidistance principle. It assumes there exist equidistance lines between the monitors (receivers) which all cross where the tag or transmitter is located. Imagine the receivers set up in a triangle, and the transmitter located at equal distance from them all. In this case equidistance exists along a line right through the middle. It is therefore impossible to extract a single point for Z. If the fourth receiver picks up the tag, more than one point for Z is less likely to exist in the space around the tag. When setting up for Z evaluation it is important to keep this in mind.

**Hostile Conditions**

If the difference in distance B-A in figure A4 is less than 4.5 meters, possibility of an error arises. The smaller the difference in distance the higher the probability of error. Errors also become more likely if the angle and distance from tag to monitor exceeds specifications.




**Overrun errors**

Overrun errors occur when two tags in the vicinity of one another both transmit at the same time or nearly the same time. The probability of an overrun error is directly proportional to the number of tags exposed to a single monitor.

Overrun error probability

OEP = (0.013*N-0.013) / (A-0.013)

Where N is number of tags and A is the duration of the Tag Signaling Cycle.

Most errors are suppressed by the system, an error tag encounter is not saved. This depends on the quality of the error rejection function of the Hx5 system. Some errors will however penetrate the defenses and be counted. There are number of ways for the user to reject these errors.

1. If a tag ID is detected by one monitor only, and isn't detected many times in a row; this is certainly an error.
2. If there is a position jump between samples, this could be an error. Application of standard deviation procedures may help eliminate these errors.

**Cost Estimate with respect to coverage and system size**

The table below shows a rough cost estimate for the XY plane coverage of an 10000 $m^2$ ( 107639 $ft^2$ ) with an open field maximum error +/- 10mm

| Item | Hexamite parts | Units | Unit Cost | Total |
|---|---|---|---|---|
| Network Controller | HX5C3 | 1 | 468 | 468 |
| Repeaters | HX5R | 10 | 75 | 750 |
| Receivers | HX5M | 1112 | 86 | 95632 |
| Telephone Cable | | 4448m | 0.4 | 1779.2 |
| RJ11 plugs | | 2224 | 0.3 | 667.2 |
| | | | Total | 99296 |

The table below shows a rough cost estimate for the XY plane coverage of an 100 $m^2$ ( 1076 $ft^2$ ) with an open field maximum error +/- 10mm

| Item | Hexamite parts | Units | Unit Cost | Total |
|---|---|---|---|---|
| Network Controller | HX5C2 | 1 | 168 | 168 |
| Repeaters | HX5R | 0 | 75 | 0 |
| Receivers | HX5M | 11 | 195 | 2145 |
| Telephone Cable | | 44 | 0.4 | 17.6 |
| RJ11 plugs | | 22 | 0.3 | 6.6 |
| | | | Total | 2337 |

The table below shows a rough cost estimate for the XY plane coverage of an 20 $m^2$ ( 215 $ft^2$ ) with an open field maximum error +/- 10mm

| Item | Hexamite parts | Units | Unit Cost | Total |
|---|---|---|---|---|
| Network Controller | HX5C | 1 | 168 | 168 |
| Repeaters | HX5R | 0 | 75 | 0 |
| Receivers | HX5M | 3 | 270 | 810 |
| Telephone Cable | | 12 | 0.4 | 4.8 |
| RJ11 plugs | | 6 | 0.3 | 1.8 |
| | | | Total | 956.6 |

**For higher or lower accuracies, wider coverage or 3D coverage contact Hexamite.**

| **Tags Average Cost estimate** | |
|---|---|
| Quantity | Price (USD) |
| 1-9 | 198 |
| 10-49 | 183 |
| 50-99 | 129 |
| 100-499 | 98 |
| 500-1000 | 79 |

**HX5 Ultrasonic Tag/Transmitter**

- Battery Operated HX5 tag
- High noise immunity
- Adjustable Position Update Rate
- Tags with Fixed Rates Available at lower cost


Ultrasonic Transmitter/Tag with transmission rate control

**HX5T1**

HX5T1 is an asynchronous HX5 ultrasonic tag. The position of the HX5T1 can be monitored and stored by the HX5M1 monitor. The tag transmits localization signals at two rates selected at random. It is battery powered and the lifetime of the battery depends on the average transmission rate or (position update rate). The battery is a commonly available AA size and replaceable. The position update rates can be selected using a membrane push button on the HX5T1. A LED on the tag flashes when the tag transmits.

**Size 20mm x 80mm x 40mm**


Ultrasonic Transmitter/Tag Sealed Weather tight IP65 compliant

| Specification | |
|---|---|
| Supply Voltage (battery) | 3 to 6.5 Volt |
| Output Power | 1 Watt |
| Range | 8m |
| Sound Pressure Level | 123 db |
| Noise Immunity | 118 db |
| Maximum Average Transmission Rate | 40 positions/second |
| Battery Life @ 20 positions/second Battery source 3.6V lithium 2000mAhrs | 15 days (15*24hrs) |
| Battery Life @ 0.2 positions/second Battery source 3.6V lithium 2000mAhrs | 4 years |

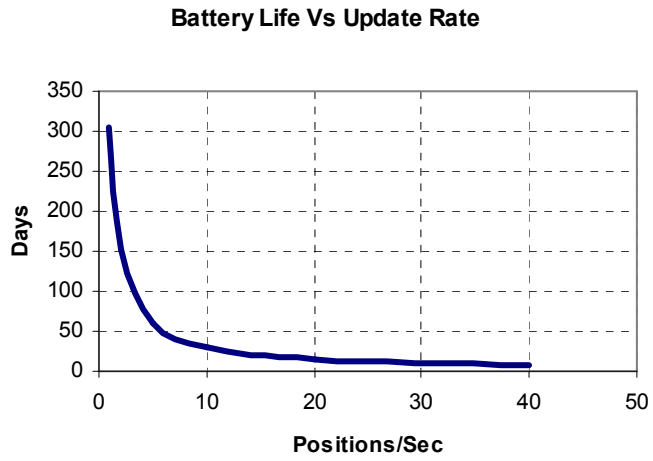
*Noise immunity is defined as the sound pressure level of a source located at the same distance from the monitor as the tag and will overwhelm the transmission from the tag to the monitor.*

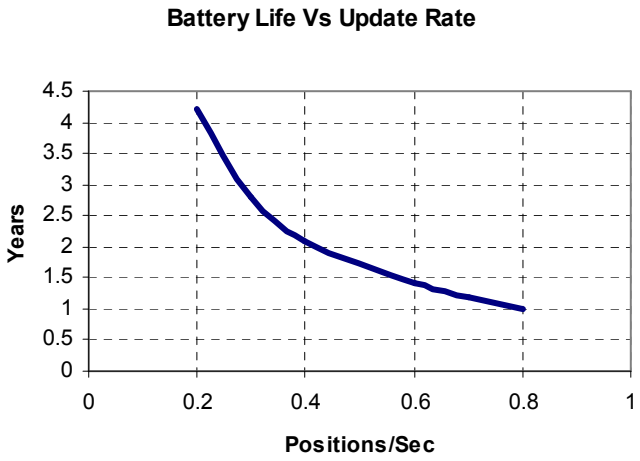
**Tag Operation**

If two HX5T1 tags are signaling simultaneously under the same monitor, the signals will distort each other and the monitor will register neither. If however one tag is significantly closer to the monitor than the other the closer tag may actually be correctly registered and positioned. The intervals by which the tags signal differ by only 50 parts per million. Hence a situation could arise where tags in similar positions, signal side by side distorting each other for a considerable period. Therefore the HX5T tags are set to signal at two intervals a and b. The length of interval b is twice the length of interval a. and interval a or b are selected at random. It is therefore improbable that two tags will signal simultaneously for long. This does however decrease the possible sampling rates of the tags. In case high speed positioning is required using a few tags, it may be advantageous to get a tag with a single rate.

**Battery Life Expectancy**

The following graphs show battery life expectancy versus position update rate. A single 3.6V lithium battery 2000mAhrs was used as reference for the graphs. The batteries are replaceable and are shipped with the HX5T1 uninstalled. Batteries for the HX5T1 are available in most places selling electronic components, and can be obtained in the USA at www.mouser.com the mouser part number is 667-TL2100P. The leads must be cut to about 1/3" or 1cm lengths and fitted into the HX5T1 battery socket. Vendors like www.digikey.com, avnet, arrow, allied electronics and etc should also carry similar batteries. In Australia www.jaycarr.com.au part number SB-1775. The HX5T1 will run on any batteries supplying 3 to 7 volts.




**Position Update Rate control**

Pressing the membrane push button on the side of the HX5T1 doubles the average identification and localization rate (position update rate) as follows:

0.1, 0.2, 0.4, 0.8, 1.6, 3.2, 6.4, 12.8, 25.6, Off (positions/second)

**HX5M1 Ultrasonic Monitor/Receiver**

HX5M1 is a HX5 ultrasonic monitor, the monitor times and stores the identification of each tag transmitting within it's range. The monitors have RJ11 data ports, the HX5C reads the data from all the monitors on the network through these ports. The data is relayed to a PC through the RS232 port and the position of the tags detected is calculated. Up to 55000 monitors may be connected for wide coverage to a single telephone cable stretching up to 10 km.


The HX5M1 has two RJ11 ports; these ports are identical. Two ports are provided to make serial connection of thousands of devices simple.

**Size 20mm x 80mm x 40mm**

Weather and watertight IP67 versions are available, contact hexamite for more information.

| Specification | |
|---|---|
| Supply Voltage | 7-16Vdc |
| Current Consumption | 60mA |
| Range | 8m |
| Maximum Reception Rate | 50 positions/second |
| Storage Capacity | 30 tag encounters |

**HX5C1-RS232 Network Controller**

HX5C is a network controller for HX5 devices. It has three RJ11 ports. One port connects to the PC RS232 port at a baud rate of 114 Kbaud. The xyz.exe program uses the PC serial port to read and store tag identifications and positions on the hard drive. The HX5C should be located within 2 meters of the PC.


The second port connects to the HX5 network at baud rate of 250Kbaud and can drive up to 128 HX5M1 receivers (for more than 128 HX5M1 a repeater is needed). The third port is a serial I/O for developers of HX5.

The power points on the HX5C are connected to the network power lines via diode, and can serve to supply power to the whole network. There is a ground pin on the HX5C which may be needed to eliminate noise on the network. Note that the network should be grounded in one place close to the PC server.

**HX5NC-USB Network Controller**

The HX5NC-USB network controller looks and works like the HX5C-RS232 series controller. It connects directly to the USB port on the computer.

**Please use regulated power supply for the HX5 network**

| Specification | |
|---|---|
| Supply Voltage | 7-16Vdc |
| Current Consumption | 40mA |
| Network Drive Capacity | 128 devices |

*Be aware that telephone lines carry limited amperes and there is a voltage drop in direct proportions to the wire length. In case of long lines, and high number of receivers it may be necessary to use local power for a far away cluster of receivers.*

**HX5R1 Repeater**

HX5R1 is a repeater, used to boost up power and communications on the network. Each repeater will drive extra 128 HX5M1 receivers. The repeater also has power points to allow the network power to be boosted from local power.

| Specification | |
|---|---|
| Supply Voltage | 7-16Vdc |
| Current Consumption | 10mA |
| Network Drive Capacity | 128 devices |

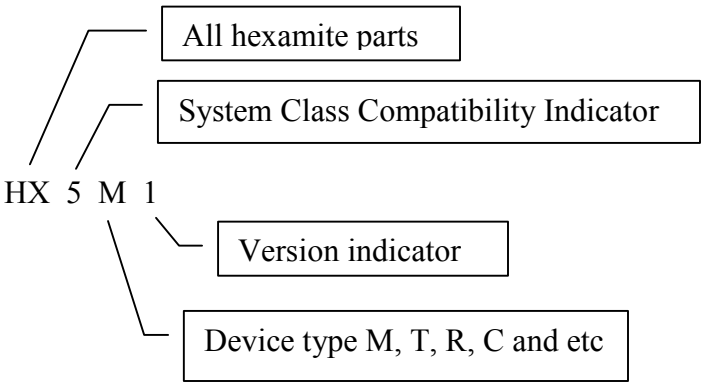
**Ordering Information**

**Standard Positioning Test Kit**

2 HX5T1 battery driven ultrasonic position transmitters (adjustable transmission rate). Dual rate HX5T1 is delivered unless Single Rate (high speed tag) is specified.
4 HX5M1 ultrasonic position receiver/monitor
1 HX5NC-RS232 or HX5NC-USB network controller
1 CDROM containing installation guide and programs hx5data.exe, xyz.exe and layout.exe

*For the standard positioning test kit the HX5, the user must obtain some telephone cable and rj11 plugs. The 4 monitors must be positioned and the position entered into a file called monData.hxm as specified above. The monitors must be connected to the HX5C as shown on the device, and the HX5C connected to the PC. The user must then run the program called xyz.exe, move the tags around and the 3D positioning file will be created. If more tags or monitors are needed these can be added at US$168 and US$290 ea.*

**Part numbers**

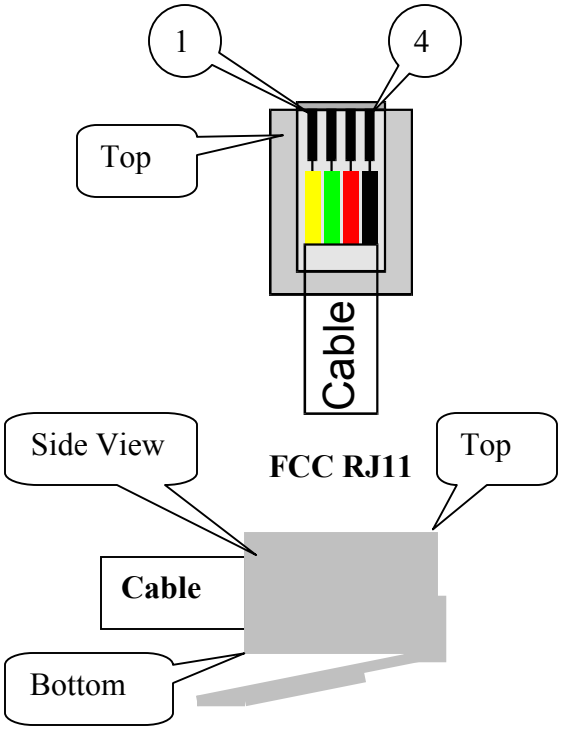


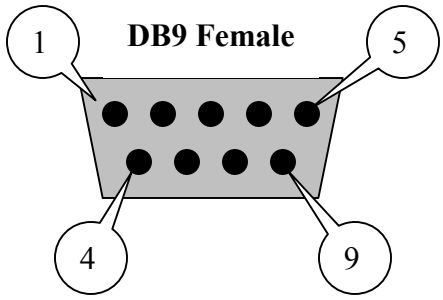
**Unpacking and Starting the HX5T**

The HX5T is shipped switched off to conserve battery power. Remove the plastic switch cover taped to the unit and press the switch down gently. Hold the switch down until you observe a flash on the LED. Each time there is a flash on the LED, the unit transmits identification and positioning signal. If the switch is held down the frequency of the flashing will increase until the unit becomes switched off. Be careful that the frequency of the signal transmission is proper for the selected update rate of the HX5M and the network controller.

**Connecting the Network Controller to a Computer**

RS232 ports on most computers are 9 pin (DB9) male type connectors. Therefore the female type shown below (see sketch) needs to be connected to the FCC RJ11 plug for the HX5NC. See the following table.




Pins on D-Subs 9 or 25 pins are always marked with the appropriate numbers for the pins as shown above.

| FCC RJ11 (pins) | DB9 (pins) | DB25 (older computers) |
|---|---|---|
| 1 (5V dc) | Not Connected | Not Connected |
| 2 (Tx) | 2 (Rx) | 3 (Rx) |
| 3 (Rx) | 3 (Tx) | 2 (Tx) |
| 4 (Ground) | 5 (Ground) | 7 (Ground) |