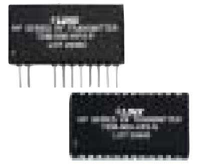
LINX TECHNOLOGIES
WIRELESS MADE SIMPLE

HIGH-PERFORMANCE
RF MODULE
TXM-900-HP3



# HP SERIES-3 TRANSMITTER DESIGN GUIDE

## DESCRIPTION:

The HP-3 RF transmitter module is the third generation of the popular HP series and offers complete compatibility and numerous enhancements over previous generations. Like its predecessors, the HP-3 is designed for the cost-effective, high-performance wireless transfer of analog or digital information in the popular 902-928MHz band. All HP-3 series parts continue to feature eight parallel selectable channels, but versions are also available which add serial selection of 100 channels. To ensure reliable performance, the transmitter employs FM/FSK modulation and a microprocessor-controlled synthesized architecture. The transmitter is pin- and footprint-compatible with all previous generations but its overall physical size has been reduced. Both SMD and pinned packages are now available. When paired with an HP-3 receiver, a reliable link is created for transferring analog and digital information up to 1000 ft. (under optimal conditions). Like all Linx modules, the HP-3 requires no tuning or additional RF components (except an antenna), making integration straightforward, even for engineers without prior RF experience.

## FEATURES:

- 8 parallel, 100 serial (PS Versions) User-Selectable Channels
- Precision Frequency Synthesized Architecture
- FM/FSK Modulation For Outstanding Performance and Noise Immunity
- Transparent Analog/Digital Interface
- High Data Rate (up to 56k)
- Wide-Range Analog Capability Including Audio (50Hz-28kHz)
- Power-Down and CTS Functions
- Cost-Effective
- Pinned or SMD Packaging
- Wide Supply Range (2.8-13V DC)
- Extended Temperature Range
- (-30°C to +85°C)
- No Production Tuning or External RF Components Required (Except Antenna)
- Compatible With Previous HP Series Modules

Revised 7/2/03

## APPLICATIONS INCLUDE:

- General Wire Elimination
- Wireless Data Transfer
- Wireless Analog / Audio
- Home / Industrial Automation
- Wireless Networks
- Remote Control
- Remote Access
- Remote Monitoring / Telemetry
- Alarm / Security Systems
- Long-Range RFID
- MIDI Links
- Voice/Music / Intercom Links

## ORDERING INFORMATION

| PART # | DESCRIPTION |
|---|---|
| TXM-900-HP3-PPO | HP-3 Transmitter (PINNED 8 CH only) |
| TXM-900-HP3-PPS | HP-3 Transmitter (PINNED 8p /100s CH) |
| TXM-900-HP3-SPO | HP-3 Transmitter (SMD 8 CH only) |
| TXM-900-HP3-SPS | HP-3 Transmitter (SMD 8p /100s CH) |
| MDEV-900-HP3-PPS | Development Kit 900MHz (Pinned Pkg.) |
| MDEV-900-HP3-SPS | Development Kit 900MHz (SMD Pkg.) |

# TRANSMITTER SPECIFICATIONS

## ABOUT THESE MEASUREMENTS

The performance parameters listed below are based on module operation at 25°C from a 5V DC supply unless otherwise noted.

| Parameter | Designation | Min. | Typical | Max. | Units | Notes |
|---|---|---|---|---|---|---|
| **POWER SUPPLY** | | | | | | |
| Input Voltage | $V_{CC}$ | 2.8 | – | 13.0 | VDC | – |
| Supply Current | $I_{CC}$ | – | 14 | 17 | mA | 1 |
| Power-Down Current | $I_{PDN}$ | – | – | 15 | µA | 2 |
| **TRANSMIT SECTION** | | | | | | |
| Transmit Frequency Range | $F_C$ | 902.62 | – | 927.62 | MHz | 3 |
| Center Frequency Accuracy | | -50 | | +50 | kHz | – |
| Available Channels | | 8 (Par.) | – | 100 (Ser.) | | 4 |
| Channel Spacing | | – | 250 | – | kHz | – |
| Occupied Bandwidth | | – | 115 | 140 | kHz | – |
| Output Power | | -3 | 0 | +3 | dBm | 5 |
| Spurious Emissions | | – | -45 | – | dBm | 6 |
| Harmonic Emissions | | – | -60 | -47 | dBm | 6 |
| Data Bandwidth | | 100 | – | 56,000 | bps | 7 |
| Analog/Audio Bandwidth | | 50 | – | 28,000 | Hz | 7 |
| Data input: | | | | | | |
| Logic low | | GND | – | 0.5 | VDC | – |
| Logic high | | 2.8 | – | 5.2 | VDC | – |
| Data Input Impedance | | – | 200 | – | kOhms | – |
| Frequency Deviation @ 3VDC | | 60 | 70 | 110 | kHz | 8 |
| Frequency Deviation @ 5VDC | | 90 | 115 | 140 | kHz | 8 |
| **ANTENNA PORT** | | | | | | |
| RF input impedance | $R_{IN}$ | – | 50 | – | Ohms | – |
| **TIMING** | | | | | | |
| Transmitter Turn-on Time | $T_1$ | – | 7 | 10 | mSec | 9 |
| Max Channel-Change Time | $T_2$ | – | 1 | 1.5 | mSec | 9 |
| **ENVIRONMENTAL** | | | | | | |
| Operational Temperature | | -30 | | +85 | °C | – |

*Figure 1: Performance Data Table*

## Notes:

1. Over entire operating voltage range
2. PDN pin low
3. Serial Mode
4. 100 Serial channels on PS versions only
5. Does not change over 3-13 VDC supply
6. Into 50 Ohms
7. Receiver will not reliably hold a DC level. See RX manual for minimum transition rate.
8. Voltage specified is modulation pin voltage
9. See page 15.

| **Absolute Maximum Ratings:** | | | |
|---|---|---|---|
| Supply voltage Vcc, using pin 7 | -0.3 | to | +18 VDC |
| Operating temperature | -30°C | to | +85°C |
| Storage temperature | -45°C | to | +85°C |
| Soldering temperature | +260°C for 10 sec. | | |
| Any input or output pin | -0.3 | to | Vcc |

***NOTE* Exceeding any of the limits of this section may lead to permanent damage of the device. Furthermore, extended operation at these maximum ratings may reduce the life or affect the function of this device.**

*Figure 2: Maximum Ratings Table*

## *CAUTION*

This product incorporates numerous static-sensitive components. Always wear an ESD wrist strap and observe proper ESD handling procedures when working with this device. Failure to observe this precaution may result in module damage or failure.

## TYPICAL PERFORMANCE GRAPHS

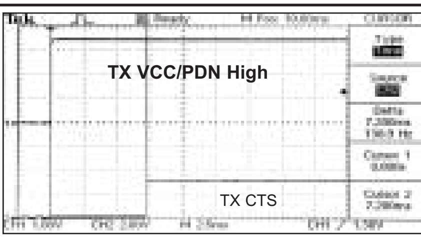



*Figure 3: Power-Up To CTS*

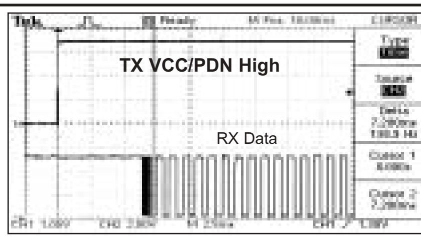



*Figure 4: TX Powerup to Valid RX Data*

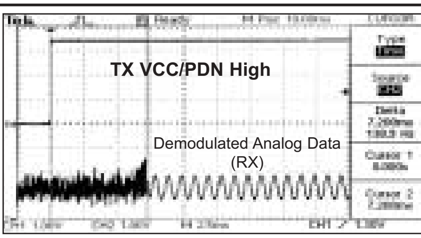



*Figure 5: TX Powerup to Valid RX Analog*

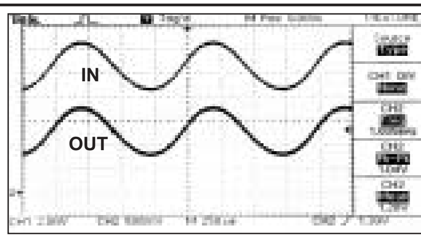



*Figure 6: Sine-Wave Modulation Linearity*

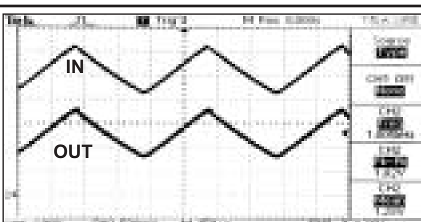



*Figure 7: Triangle-Wave Modulation Linearity*

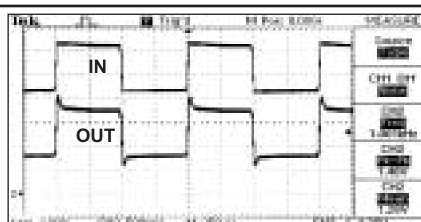



*Figure 8: Square-Wave Modulation Linearity*

# PIN DESCRIPTION

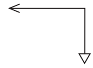
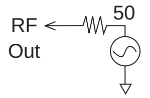
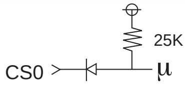
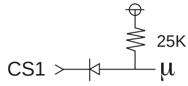
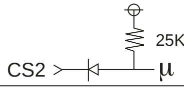
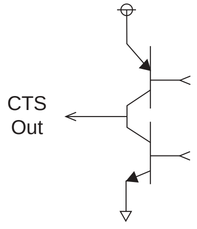
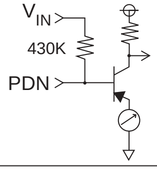
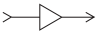
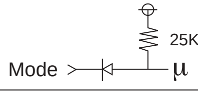
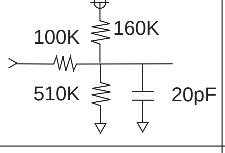
| PIN # SMD | PIN # Pinned | PIN Name | Equivalent CTK | Description |
|---|---|---|---|---|
| 1<br>3<br>13<br>20 | 1 | GND |  | Ground |
| 2 | 2 | RF/ANT Out |  | 50 Ohm RF Output |
| 5 | 3 | CS0 |  | Channel Select 0 |
| 6 | 4 | CS1/SS CLOCK |  | Channel Select 1/Serial Select Clock |
| 7 | 5 | CS2/SS DATA |  | Channel Select 2 /Serial Select Data |
| 8 | 6 | CTS |  | Clear-to-Send<br>Output |
| 9 | 7 | PDN |  | Power Down<br>(Active Low) |
| 10 | 8 | VCC |  | Voltage Input 2.8-16V |
| 11 | 9 | GND/MODE |  | Ground/Mode |
| 12 | 10 | Analog In/Data In |  | Digital/Analog Input<br>*See text "Inputting Digital Data"* |
| 4<br>14-19<br>21-24 | | N/C | SMD (Only) | No Connection |

*Figure 9: Pin Functions and Equivalent Circuits*

# PHYSICAL PACKAGING

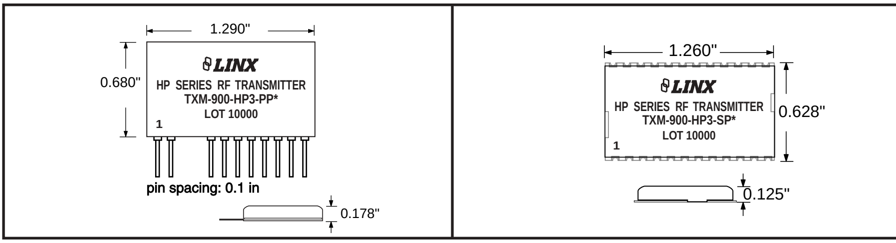



*Figure 10: Transmitter Physical Package*

The transmitter is available in two package styles. The pinned SIP style is designed for through-hole application and has 10 pins spaced at 0.1" intervals. Pin 1 is on the far left of the board when viewed from the front. The package may be inserted at right angles or bent to lie down (with the cover facing up) on the PCB. Avoid repeated bending of the pins as they may weaken and break.

The surface-mount version is housed in a 24 pad hybrid SMD package which has been designed to facilitate both hand and automated assembly. Pin one is on the lower left when viewed as shown above. Castellation grooves have been provided for ease of hand soldering and inspection.

# RECOMMENDED PAD LAYOUT

The following drawings illustrate the recommended circuit-board footprints for the HP-3 series transmitter modules. Be sure to also review the physical layout and the antenna recommendations contained elsewhere in this guide.

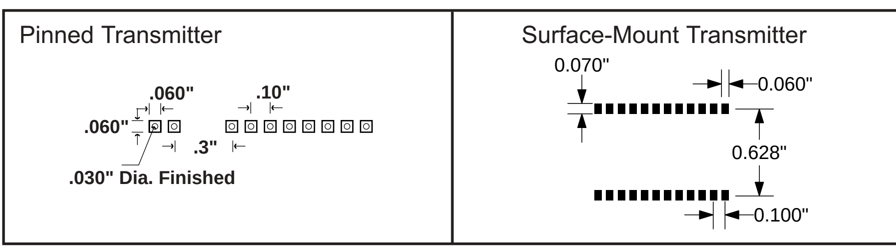



*Figure 11: Suggested PCB Footprint*

# ENCAPSULATION NOTICE

In some applications the designer may wish to encapsulate the product's circuit board. Among the common reasons for doing so are environmental protection and security. The dielectric constant of encapsulation and potting materials varies and can adversely affect transmitter performance. For this reason, Linx does not recommend the encapsulation of our products. Doing so will void all product warranties. It should be noted, however, that customers have reported success with a variety of encapsulation materials and techniques. Should you choose to encapsulate your product, careful testing should be conducted to determine the suitability of the chosen material.

# PRODUCTION GUIDELINES

## Pinned Transmitter Hand Assembly

The SIP module pins may be hand or wave-soldered. The module should not be subjected to reflow. Linx recommends wash-free manufacturing techniques. The modules are wash-resistant, but are not hermetically sealed. If a wash is used, a drying time, sufficient to allow the evaporation of any moisture which may have migrated into the module, must be allowed prior to applying electrical power. If the wash contains contaminants, transmitter performance may be adversely affected even after drying.

## SMD Transmitter Hand Assembly

The SMD version is housed in a hybrid SMD package which has been designed to support hand or automated reflow techniques. The package's primary mounting surface is the pads located on the bottom of the module. Since these pads are inaccessible during mounting, plated castellations run up the sides of the module to facilitate solder wicking. This allows for very quick and efficient hand soldering for prototyping and small volume production.

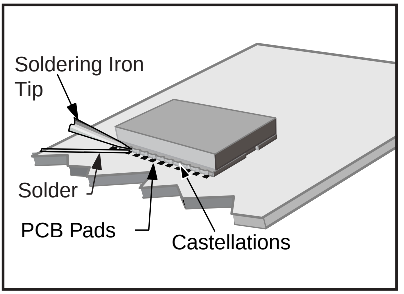



*Figure 12: Soldering Technique*

If the recommended pad placement has been followed, the pad on the board will extend slightly past the edge of the module. Touch both the PCB pad and the module castellation with a fine soldering tip. Tack one module corner first, then work around the remaining attachment points being careful not to exceed the solder times listed below.

Care should be taken, especially when hand-soldering, not to use excessive amounts of flux as it will wick under the module and potentially impair its function. In many cases, no-clean solder is the best choice. The modules are wash-resistant, but are not hermetically sealed. Linx recommends wash-free manufacturing techniques. If a wash is used, a drying time, sufficient to allow any moisture which may have migrated into the module to evaporate, must be allowed prior to applying electrical power. If the wash contains contaminants, transmitter performance may be adversely affected even after drying.

## Absolute Maximum Solder Times

**Hand-Solder Temp. TX +225°C for 10 Sec.**
**Hand-Solder Temp. RX +225°C for 10 Sec.**
**Recommended Solder Melting Point +180°C**
**Reflow Oven: +220° Max. (See adjoining diagram)**

For high-volume assembly, most users will want to auto-place the modules. SMD versions of the modules have been designed to maintain compatibility with most pick-and-place equipment, however, due to the module's hybrid nature certain aspects of the automated assembly process are far more critical than for other component types.

Following are brief discussions of the three primary areas where caution must be observed.

### Reflow Temperature Profile

The single most critical stage in the automated assembly process is the reflow process. The reflow profile below should not be exceeded since excessive temperatures or transport times during reflow will irreparably damage the modules. Assembly personnel will need to pay careful attention to the oven's profile to ensure that it meets the requirements necessary to successfully reflow all components while remaining within the limits mandated by the modules themselves.

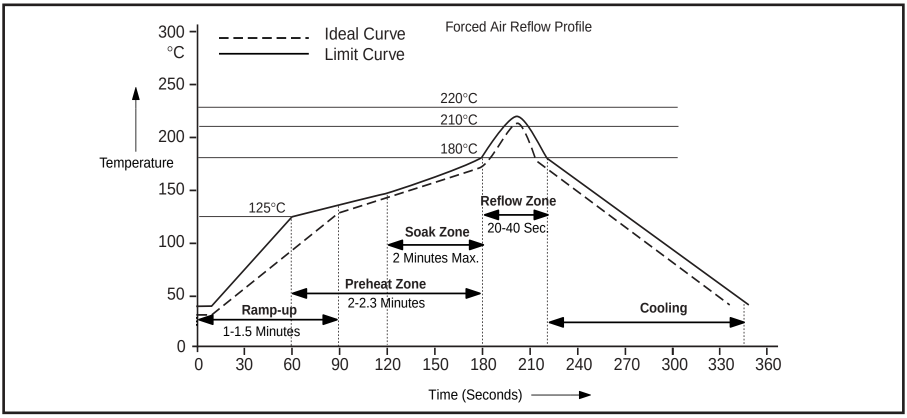



*Figure 13: Maximum Reflow Profile*

### Shock During Reflow Transport

Since some internal module components may reflow along with the components placed on the board being assembled, it is imperative that the module not be subjected to shock or vibration during the time solder is liquidus.

### Washability

The modules are wash-resistant, but are not hermetically sealed. Linx recommends wash-free manufacturing techniques, however, the modules can be subjected to a wash cycle provided that a drying time is allowed prior to applying electrical power to the parts. The drying time should be sufficient to allow any moisture which may have migrated into the module to evaporate, thus eliminating the potential for shorting damage during power-up or testing. If the wash cycle contains contaminants, transmitter performance may be adversely affected, even after drying.

# THEORY OF OPERATION

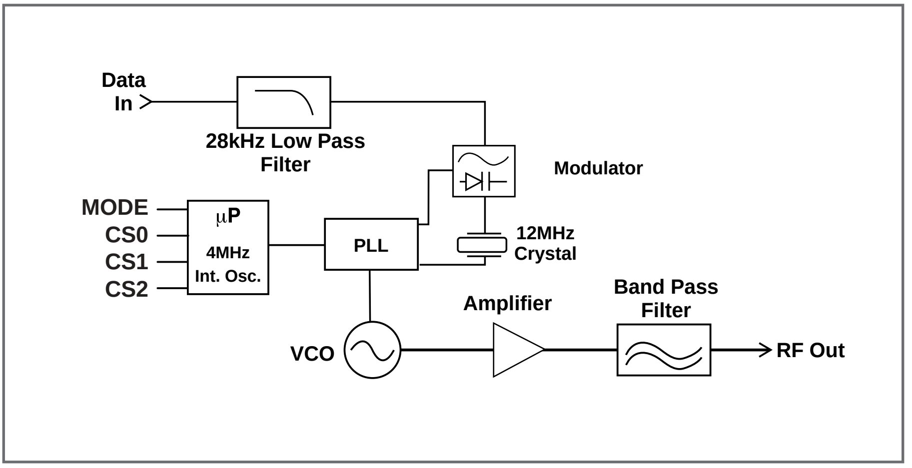



*Figure 14: HP-3 Series Transmitter Block Diagram*

The TXM-HP3 is a high-performance, multi-channel RF transmitter capable of transmitting both analog (FM) and digital (FSK) information. FM/FSK modulation offers significant advantages over AM or OOK modulation methods including increased noise immunity and the receiver's ability to "capture" in the presence of multiple signals. This is especially helpful in crowded bands like those in which the HP-3 operates.

Let's take a brief look at each transmitter section. A precision 12.00MHz Voltage-Controlled Crystal Oscillator (VCXO) serves as the frequency reference for the transmitter. Incoming signals are filtered to limit their bandwidth and then used to directly modulate this reference. Direct reference modulation inside the loop bandwidth allows a fast startup while allowing a wide modulation bandwidth and near DC modulation capability. This results in accurate reproduction of analog and digital content and eliminates the need for code balancing.

The modulated 12.00MHz reference frequency is applied to the Phase-Locked Loop (PLL). The PLL, combined with a 902-928MHz VCO, forms a stable frequency synthesizer that can be programmed to oscillate at the desired transmit frequency. An on-board micro-controller manages the PLL programming functions and greatly simplifies user interface. The micro-controller reads the channel-selection lines and programs the on-board synthesizer. This frees the designer from complex programming requirements and allows for manual or software channel selection. The micro-controller also monitors the status of the PLL and indicates when the transmitter is stable and ready to transmit data by raising the CTS line high.

The PLL locked carrier is amplified and buffered to isolate the VCO from the antenna and to increase the output power of the transmitter. The output of the buffer amplifier is connected to a filter network which suppresses harmonic emissions. Finally, the signal reaches the single-ended antenna port, which is matched to 50 ohms to support commonly available antennas, such as those manufactured by Linx.

# BOARD LAYOUT GUIDELINES

If you are familiar with RF you may be concerned about specialized layout requirements. Fortunately, by carefully adhering to a few basic design and layout rules transmitter integration is generally very straightforward.

Page 5 shows the suggested PCB footprint for the HP-3 transmitter. A groundplane (as large as possible) should be placed on a lower layer of your PC board opposite the transmitter. This groundplane can also be critical to the performance of your antenna which will be discussed later in the manual.

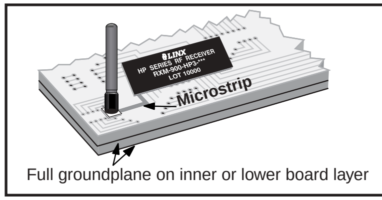


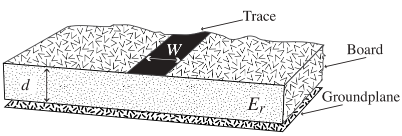

*Figure 15: Groundplane Treatment*

The transmitter should be kept away from other components on your PCB, especially high-frequency noise sources such as an oscillator or switching supply.

To mount a pinned version of the transmitter parallel to the PC board, bend it over so that the plastic cover faces away from the board.

Do not route PCB traces directly under SMD packaged versions. The underside of the module has numerous signal-bearing traces and vias which could short or couple to traces on the product's circuit board.

The trace from the transmitter to the antenna should be kept as short as possible. For runs greater than 1/4 inch use 50-ohm coax or a 50-ohm microstrip transmission line as shown below. Handy software for calculating microstrip lines is available on the Linx website (www.linxtechnologies.com).




$$E_e = \frac{E_r+1}{2} + \frac{E_r-1}{2} \cdot \frac{1}{\sqrt{1+12d/W}}$$

$$Z_0 = \begin{cases} \dfrac{60}{\sqrt{E_e}} \cdot \ln\left(\dfrac{8d}{W} + \dfrac{W}{4d}\right) & \text{For } \dfrac{W}{d} \le 1 \\[2ex] \dfrac{120\pi}{\sqrt{E_e} \cdot \left(\dfrac{W}{d} + 1.393 + 0.667 \cdot \ln\left(\dfrac{W}{d} + 1.444\right)\right)} & \text{For } \dfrac{W}{d} \ge 1 \end{cases}$$

$E_r$ = Dielectric constant of PCB material

| Dielectric Constant | Width/Height (W/d) | Effective Dielectric Constant | Characteristic Impedance |
|---|---|---|---|
| 4.8 | 1.8 | 3.59 | 50.0 |
| 4 | 2 | 3.07 | 51.0 |
| 2.55 | 3 | 2.12 | 48.0 |

*Figure 16: Microstrip Formulas (Er = Dielectric constant of pc board material)*

The typical output power of the HP-3 transmitter is right at Part-15 limits. Sometimes, it is necessary to slightly attenuate the output to compensate for antenna gain. This is accomplished using a three-resistor attenuation network as shown. While this network is often referred to as a “T” pad the actual resistor orientation is usually not critical. Use only surface-mount type resistors grouped closely. The series pads may be bridged if the network is not needed. Further details can be found in application note #00150 - "Use and Design of T-Attenuation Pads".

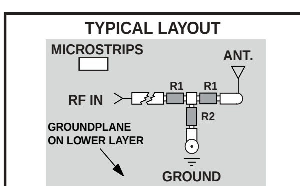



*Figure 17: T-pad Layout*

## POWER SUPPLY GUIDELINES

The user must provide a clean source of power to the transmitter to ensure proper operation. The HP-3 incorporates a precision low-dropout regulator on-board which allows operation over an input voltage range of 2.8 to 13 VDC. Figure 18 shows a typical supply filter. This filter should be placed close to the module's supply lines. Its actual values will depend on the type and frequency of noise present in the user's product.

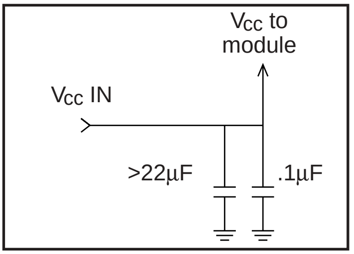


*Figure 18: Typical Supply Filter*

The HP-3 can be put into an ultra-low-current (<15µA) power-down mode by holding the PDN pin low. If the PDN pin is left open or held high, the transmitter will turn on. In power-down mode, the transmitter is completely shut down.

## POWER-UP SEQUENCE

The HP-3 transmitter is controlled by an on-board microprocessor. When power is applied, a start-up sequence is executed. At the end of the start-up sequence, the transmitter is ready to transmit data.

Figure 19 shows the start-up sequence. This sequence is executed when power is applied to the VCC pin or when the PDN pin is cycled from low to high.

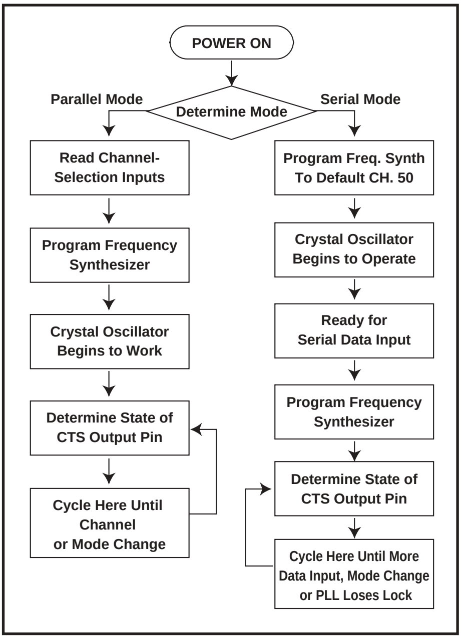


*Figure 19: Start-up Sequence*

On power-up, the on-board microprocessor reads the external channel-selection lines (parallel mode) or serial channel input (serial mode) and sets the frequency synthesizer to the appropriate channel. Figure 3 on page 3 shows the typical turn-on response time for an HP-3 transmitter. When the frequency synthesizer has locked on to the proper channel frequency, the circuit is ready to accept data. This is acknowledged by the CTS line transitioning high. The module will then transmit analog or digital data from the user's circuit.

The module can be put into an ultra-low-current (<15µA) power-down mode by holding the PDN pin low. This removes all power from the transmitter's circuitry. If PDN is left floating or held high, the transmitter will wake up and begin normal operation. No transmitter functions work when PDN is low.

# CHANNEL SELECTION

## Parallel Selection

All HP-3 transmitter models feature eight parallel selectable channels. Parallel mode is selected by grounding the mode pin. In this mode, channel selection is determined by the logic states of pins CS0-CS2 as shown in Figure 20. In this table a "0" represents ground and a "1" the positive supply. The on-board microprocessor performs all PLL loading functions, eliminating external programming and allowing channel selection via DIP switches or a product's processor.

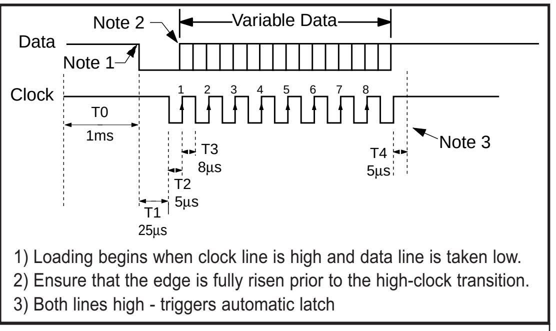
| CS2 | CS1 | CS0 | Channel | Frequency |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 903.37 |
| 0 | 0 | 1 | 1 | 906.37 |
| 0 | 1 | 0 | 2 | 907.87 |
| 0 | 1 | 1 | 3 | 909.37 |
| 1 | 0 | 0 | 4 | 912.37 |
| 1 | 0 | 1 | 5 | 915.37 |
| 1 | 1 | 0 | 6 | 919.87 |
| 1 | 1 | 1 | 7 | 921.37 |

*Figure 20: Parallel Channel Select Table*

## Serial Selection

In addition to the parallel mode, PS versions of the HP-3 also feature 100 serially selectable channels. The serial mode is entered when the mode pin is left open or held high. In this condition CS1 and CS2 become a synchronous serial port with CS1 serving as the clock line and CS2 as the data line. The module is easily programmed by sending and latching the binary number (0-100) of the desired channel (*see page 22 for channel selection table*). With no additional effort the module's on-board microprocessor handles the complex PLL loading functions.

The serial mode is straightforward, however, minimum timings and bit order must be followed. Loading is initiated by taking the clock line high and the data line low as shown. The eight-bit channel number is then clocked in one bit at a time with the LSB first.




| | | |
|---|---|---|
| **(T0)** | **Minimum time between packets or prior to data startup** | **1mS min.** |
| **(T1)** | **Data-LO/Clock-HI to Data-LO/Clock-LO** | **25µS min.** |
| **(T2)** | **Clock-LO to Clock-HI** | **5µS min.** |
| **(T3)** | **Clock-HI to Clock-LO** | **8µS min.** |
| **(T4)** | **Data-HI/Clock-HI** | **5µS min.** |
| **Total Packet Time** | | **157µS min.** |

*Figure 21: PLL Serial Programming Timing Table*

There is no maximum time for this process, only the minimum times which must be observed. After the eighth bit both the clock and data lines should be taken high to trigger the automatic data latch. A typical software routine can complete the loading sequence in under 200µS. A sample routine is available on the Linx website.

*NOTE: When the module is powered up in the serial mode it will default to channel 50 until programmed by user software. This allows testing apart from external programming and prevents out-of-band operation. When programmed properly, the dwell time on this default channel can be less than 200µS. Channel 50 is not counted as a usable channel since transmitters defaulting to the channel might interfere with a transmitter intentionally occupying the channel. If a loading error occurs, such as a channel number >100 or a timing problem, the receiver will default to serial channel 0. This is useful for debugging as it verifies serial port activity.*

## CTS OUTPUT

The Clear-To-Send (CTS) output goes high to indicate the transmitter PLL is locked and the module is ready to accept data. In a typical application, a micro-controller will raise the PDN line high (powering-up the transmitter) and begin to monitor the CTS line. When the line goes high, the micro-controller would start sending data. It is not necessary to use the CTS output. In applications where CTS is not used, the user's circuit should wait a minimum of 10mSec after raising the PDN pin high before transmitting data. If data is being sent redundantly, there is generally no need to monitor the CTS pin or to wait a fixed time.

## INPUTTING ANALOG SIGNALS

The HP-3 series transmitter is capable of sending a wide range of analog signals including audio. The ability of the HP-3 to send combinations of audio and data also opens new areas of opportunity for creative design.

Simple or complex analog signals within the specified analog bandwidth and input levels may be connected directly to the transmitter's DATA pin. The transmitter input is high impedance (200k) and can be directly driven by a wide variety of sources ranging from a single frequency to complex content such as voice or music. Analog signals at the data input pin may range from 50 Hz to 28kHz. The Typical Performance Graphs on page 3 of this manual illustrate the modulation linearity for a variety of simple waveforms.

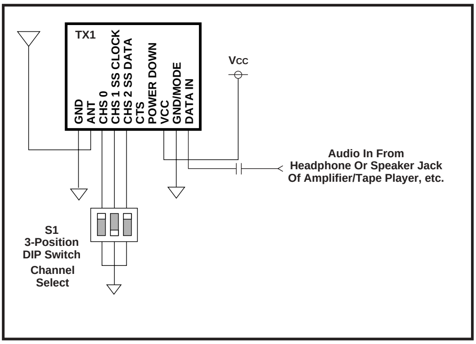



*Figure 22: Typical Voice Transmitter*

The HP3 is a single supply device and as such is not capable of operating in the negative voltage range, therefore analog sources should typically provide a 0V to 3V, but not more than 5V P-P, maximum waveform and should, in most cases, be AC-coupled into the DATA pin to achieve the best performance. The size of the coupling capacitor should be large enough to ensure the passage of all desired frequencies and, at the same time, small enough to allow the start-up time desired. After the AC signal passes into the modulation circuit it will be automatically adjusted to the optimum DC offset by an internal voltage divider. Since the modulation voltage applied to the DATA pin determines the carrier deviation, distortion can occur if the DATA pin is over-driven. The actual level of the input waveform should be adjusted to achieve optimum in-circuit results for your application.

The illustration above shows the simplicity of transmitting audio with the HP-3 transmitter. In applications where higher audio quality is required, an external compandor such as a Phillips SA576, may be employed to increase dynamic range and reduce noise. The HP-3 is capable of providing audio quality comparable to a radio or intercom. When true high-fidelity audio is required, the HP will probably not be the best choice, as it has been optimized for data. A device designed specifically for high quality audio should be utilized instead.

# INPUTTING DIGITAL DATA

The data input pin may be directly connected to virtually any digital peripheral including microcontrollers, encoders, and UART's. The data input has an impedance of 200kΩ and can be used with any data that transitions from 0V to a 3V-5V peak amplitude within the specified bandwidth of the module. While it is possible to send data at rates higher than specified, the internal data filter will cause severe roll off and attenuation.

Many RF products require a fixed data transition rate or place tight constraints on the mark/space ratio of the data being sent. Thankfully, the HP-3 transmitter architecture eliminates such considerations and allows virtually any signal, including PWM, Manchester and NRZ data to be sent at rates from 100bps to 56kbps. This is accomplished by directly modulating the PLL's frequency reference within the loop filter bandwidth. By doing so, the loop filter can be optimized for rapid startup while allowing near DC modulation.

Unlike a radio modem the HP-3 does not encode or packetize the data in any manner. This transparency gives the designer great freedom in software and protocol development. A designer may also find creative ways to utilize the ability of the transmitter to accept both digital and analog signals. For example, an application might transmit voice in analog then send out a digital control command. Such mixed mode systems, which combine analog signals and data can greatly enhance the function and versatility of many products without a significant increase in implementation cost.

It is always important to think of an RF link as a total system taking into account both the transmitter and receiver characteristics. The incoming data must not only be compatible with the transmitter but also within the capability of the receiver to reproduce it. For example, if the transmitter were sending a 255 (0FF hex) continuously the receiver would view the stream of high bits as a DC level. The receiver would hold that level until a transition was required to meet its minimum transition frequency requirement. If no transition occurred, data integrity could not be guaranteed. The HP-3 transmitter has been designed for compatibility with all generations of HP receivers. While it can potentially be used with receivers from other manufacturers we do not recommend it. The easiest application and field reliability will be obtained when HP family components are used for the entire link.

# PROXIMITY OPERATION

Multiple transmitters may be active on separate channels so long as an adjacent channel's signal does not enter the receiver at a level exceeding the rejection capability of the receiver. In serial mode the channels are closely spaced and will not all be useable in proximity. The large number of channels is not meant to imply that all can be successfully used in close proximity. The high channel count is provided to accommodate hopping, allow compatibility with a broad range of receiver frequencies, and allow agility in avoiding other interference sources. In cases where the modules are combined to form a transceiver they should be operated in half-duplex, meaning that only the transmitter or receiver is active at any time. Full-duplex operation is possible but will result in reduced range due to receiver desensing from the closely adjacent transmitter..

# DATA CONSIDERATIONS

Once an RF link has been established, the challenge becomes how to effectively transfer information across it. For simple control or status signals, such as button presses or switch closures, consider using an encoder and decoder IC set. These chips are available from several manufacturers including Linx, Microchip, Holtek, and Motorola. These chips take care of all encoding, error checking, and decoding functions. They generally provide a number of inputs to which switches can be directly connected, and address or security bits to prevent unintentional activation. These IC's are an excellent way to avoid protocol development and bring basic remote control/status products quickly and inexpensively to market.

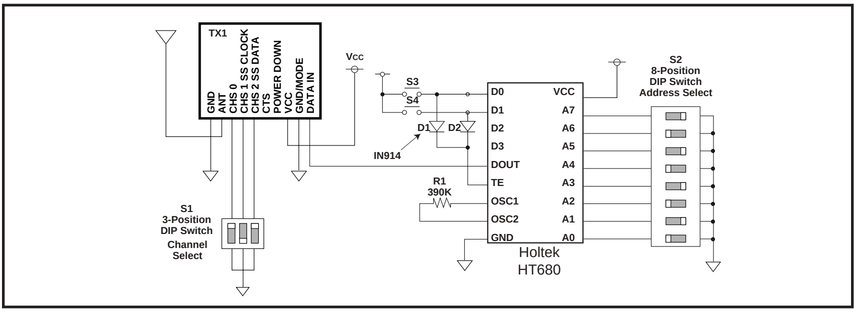



*Figure 23: Typical Application: Remote-Control Transmitter*

In most applications the modules will be interfaced to a microprocessor. A UART may be employed or an output pin of the microprocessor "bit-banged" to create a data stream. While many RF solutions impose complex formatting and balancing requirements, the HP-3 series was designed to be as transparent as possible. The HP-3 does not encode or packetize the data in any manner. This transparency gives the designer tremendous flexibility in the structure of a protocol. Of course the performance and reliability of the link are dependent on the quality of external software and hardware. To properly apply the transmitter, it is critical to understand the differences between a wired and a wireless environment. At each point in the system there are timing and data-corruption issues that should be understood and accounted for. The following section provides a brief overview of these issues. You may also wish to read Application note 161 (Considerations for Sending Data Using the HP-3 Series) prior to beginning code development.

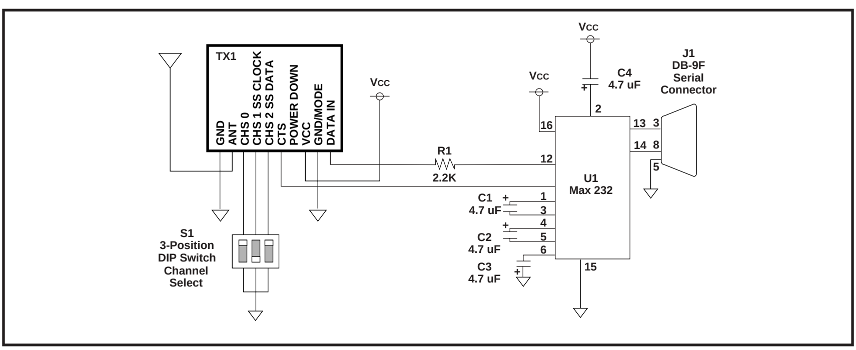



*Figure 24: Typical Application: RS-232 Interface*

# TIMING CONSIDERATIONS

Timing plays a key role in link reliability especially when the modules are being rapidly turned on and off or hopping channels. Unlike a wire, allowance must be made for the programming and settling times of both the transmitter and receiver otherwise portions of the signal being sent will be lost. There are two major timing considerations the engineer must be aware of when designing with the HP-3 Series transmitter. These are shown in the table below. Remember the stated timing parameters assume a stable supply of 2.8 volts or greater. They do not include the charging times of external capacitance on the module's supply lines, the overhead of external software execution, or power supply rise times.

| Parameter | Description | Max. |
|---|---|---|
| $T_1$ | Transmitter Turn-on Time | 10mSec |
| $T_2$ | Max Channel-Change Time (Time to Valid Data) | 1.5mSec |

$T_1$ is the maximum time required for the transmitter to power-up and lock on-channel. This time is measured from the application of VCC to the CTS output transitioning high.

$T_2$ is the worst-case time needed for a powered-up module to switch between channels from a valid channel selection. This time does not include external overhead for loading a desired channel in the serial channel-selection mode.

Normally, the transmitter will be turned off after each transmission. This is courteous use of the airwaves and reduces power consumption. The transmitter may be shutdown by switching its supply or the PDN pin. In power-down the module is completely shut down. When the transmitter is again powered up allowance must be made for the requirements above.

In many cases the transmitter will lock more quickly than the times indicated. In instances where turn-around time or power consumption are critical the CTS pin should be monitored so data can be sent immediately upon transmitter readiness.

# PROTOCOL CONSIDERATIONS

As previously indicated, the module's transparency allows for virtually unlimited protocol types and techniques.This section is meant only to illustrate general issues a designer should address to ensure product reliability in the field. Your application may call for or benefit from an entirely different protocol structure.

It is a good idea to structure the data being sent into small packets so that errors can be managed without affecting large amounts of data. Packets should be transmitted without space between bytes. When using a UART the following packet format is often followed:

[ uart sync byte ] [ start byte ] [ data packet ]

The UART sync-byte is used to ensure that the start-bit for the start-byte will be correctly detected. It is a single byte with a value of 255 (0FF hex). A start-byte often follows the sync-byte to intelligently qualify the data-packet which will follow. Detection of the start-byte would be performed by the computer or microcontroller connected to the receiver.

## PROTOCOL CONSIDERATIONS (CONT.)

The procedure here is protocol-dependent, but to illustrate let's consider the packet format outlined on the preceding page being sent to a UART. A UART interprets the start-bit of a byte as a 1-0 transition. When the incoming data is 101010, or hash, it is hard actually to find the start bit. This problem is solved by the UART sync-byte. The purpose of the sync-byte is to create a high marking period of at least a byte-length so that the start bit of the following start-byte can be correctly recognized.

The start-byte is used by the receiving computer or microcontroller to intelligently identify the beginning of a data packet. The start-byte value should be chosen so that it does not appear in the data stream. Otherwise, a microntroller may "wake up" in the middle of a packet and interpret data in the packet as a valid start-byte. There are many other ways to organize protocol if this proves impractical.

There is always a possibility of bursting errors from interference or changing signal conditions causing corruption of the data packet, so some form of error checking should be employed. A simple checksum or CRC could be used. Once an error is detected the protocol designer may wish to simply discard the corrupt data or develop a scheme for correcting it or requesting its retransmission.

## INTERFERENCE CONSIDERATIONS

It must be recognized that many bands, such as those in which the HP-3 operates, are widely used, and the potential for conflict with other unwanted sources of RF is very real. All RF products are at risk from interference but its effects can be minimized by better understanding its characteristics.

Interference can manifest itself in many ways. Low-level interference will produce noise and hashing on the output and reduce the link's overall range. Thanks to the capture properties of an FM system, the receiver will still function when an intended signal is present at a higher level than the interference.

Another type of interference can be caused by higher-powered devices such as hopping spread-spectrum devices. Since these devices move rapidly from frequency to frequency they will usually cause short, intense losses of information. Such errors are referred to as bursting errors and will generally be dealt with through protocol.

High-level interference is caused by products sharing the same frequency or from near-band high-power devices. Fortunately, this type of interference is less common than those mentioned previously, but in severe cases can prevent all useful function of the affected device. It is in these cases that the frequency agility offered by the HP-3 is especially useful.

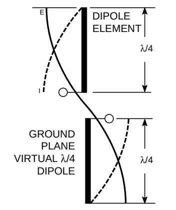
Although technically it is not interference, multipath is also a factor to be understood. Multipath is a term used to refer to the signal cancellation effects that occur when RF waves arrive at the receiver in different phase relationships. This is particularly a factor in interior environments where objects provide many different reflection paths. Multipath results in lowered transmitter signal levels at the receiver and thus shorter useful distances for the link.

The receiver's Received Signal Strength Indicator (RSSI) output can be used to qualify the presence and strength of interference and identify the best channels for use in a given environment. Refer to the HP-3 receiver guide for more details.

# GENERAL ANTENNA RULES

The following general rules should help in maximizing antenna performance:

1. Proximity to objects such as a user's hand or body, or metal objects will cause an antenna to detune. For this reason the antenna shaft and tip should be positioned as far away from such objects as possible.
2. Optimum performance will be obtained from a 1/4- or 1/2-wave straight whip mounted at a right angle to the groundplane. In many cases, this isn't desirable for practical or ergonomic reasons; thus, an alternative antenna style such as a helical, loop, patch, or base-loaded whip may be utilized and the corresponding sacrifice in performance accepted.
3. If an internal antenna is used, keep it away from other metal components, particularly large items like transformers, batteries, and PCB tracks and groundplanes. In many cases, the space around the antenna is as important as the antenna itself.
4. In many antenna designs, particularly 1/4-wave whips, the groundplane acts as a counterpoise, forming, in essence, a 1/2-wave dipole. For this reason adequate groundplane area is essential. The groundplane can be a metal case or ground-fill on the circuit board. Ideally, the groundplane to be used as counterpoise should have a surface area ≥ the overall length of the 1/4-wave radiating element and be oriented at a 90° angle. Such an orientation is often not practical due to size and configuration constraints. In these instances a designer must make the best use of the area available to create as much groundplane in proximity to the base of the antenna as possible. In instances where the antenna is remotely located or the antenna is not in close proximity to a circuit board plane or grounded metal case, a small metal plate may be fabricated to maximize antenna performance.



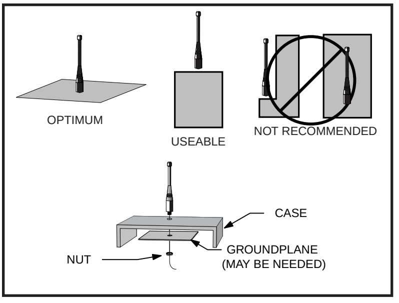




*Figure 25: Antenna Orientations*

5. Remove the antenna as far as possible from potential interference sources such as switching power supplies, oscillators, motors and relays. Remember, the single best weapon against such problems is attention to placement and layout. Filter the module's power supply with a high-frequency bypass capacitor. Place adequate groundplane under all potential sources of noise. Shield noisy board areas whenever practical.
6. In some applications it is advantageous to place the receiver and its antenna away from the main equipment. This avoids interference problems and allows the antenna to be oriented for optimum RF performance. Always use 50Ω coax, such as RG-174, for the remote feed.

# ANTENNA CONSIDERATIONS

The choice of antennas is one of the most critical and often overlooked design considerations. The range, performance, and legality of the transmitter is critically dependent on the antenna utilized. While adequate antenna performance can often be obtained by trial and error methods, professionally designed antennas, such as those offered by Linx, can provide superior performance, repeatability and legal compliance. For complete details on the Linx antenna line, visit the Linx website at www.linxtechnologies.com, or call (800)736-6677

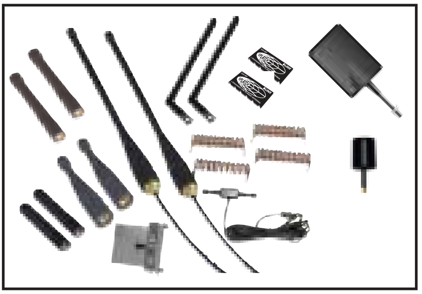


*Figure 26: Linx Antennas*

*The following sections look at some of the basic considerations involved in the design and selection of antennas. For a more comprehensive discussion please refer to Linx applications note #00500 "Antennas: Design, Application, Performance".*

# CONNECTOR OPTIONS

COST-EFFECTIVE CONNECTOR Linx LINE FCC-COMPLIANT

The FCC requires that antennas designed for use on Part 15 products be either permanently attached, or utilize a unique and proprietary connector not available to the general public. In cases where the antenna needs to be removable, Linx offers a full line of connectors designed to comply with these requirements.

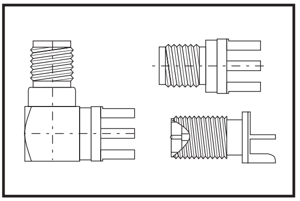


*Figure 27: Linx Connectors*

# ANTENNA SHARING

In cases where a transmitter and receiver module are combined to form a transceiver it is often advantageous to share a single antenna. To accomplish this an antenna switch must be used to provide isolation between the modules. There is a wide variety of antenna switches available which are cost-effective and straight-forward to use. Among the most popular are switches from Alpha and NEC. Look for an antenna switch that has high isolation and low loss at the desired frequency of operation. Generally, the TX or RX status of a switch will be controlled by a product's microprocessor, but selection may also be made manually by the user. In some cases where the characteristics of the TX and RX antennas need to be different or switch losses are unacceptable it may be more appropriate to utilize two discrete antennas.

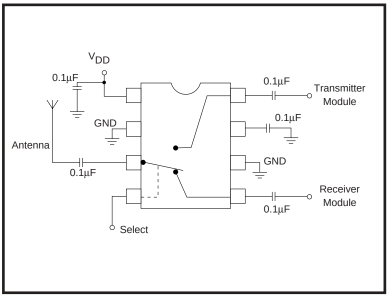
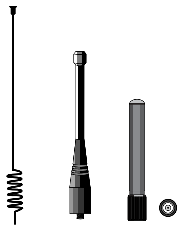



*Figure 28: Typical Antenna Switch*

# COMMON ANTENNA STYLES

The antenna is a critical and often overlooked component which has a significant effect on the overall range, performance and legality of an RF link. There are hundreds of antenna styles that can be employed with the HP-3 Series. Following is a brief discussion of styles commonly utilized in compact RF designs.

## Whip Style



A whip-style monopole antenna provides outstanding overall performance and stability. A low-cost whip can be easily fabricated from wire or rod, but most product designers opt for the consistent performance and cosmetic appeal of a professionally made model. To meet this need, Linx offers a wide variety of straight and reduced-height whip-style antennas in permanent and connectorized mounting styles.

The wavelength of the operational frequency determines an antenna's overall length. Since a full wavelength is often quite long, a partial 1/4-wave antenna is normally employed. Its size and natural radiation resistance make it well-matched to Linx modules. The approximate length for a straight 1/4-wave antenna can be easily found using the formula below. It is also possible to reduce the overall height of the antenna by using a helical winding; therefore, the physical appearance is not always an indicator of the antenna's frequency.

1/4-wave wire length frequencies:
**433MHz = 6.5"**
**868MHz = 3.24"**
**902-928MHz = 3.06"**

$$L = \frac{234}{F_{MHz}}$$

Where:
*L=length in feet of quarter-wavelength*
*F=operating frequency in megahertz*

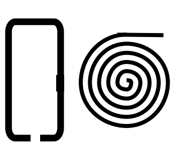
$$\frac{234}{916MHz} = .255$$

.255 x 12" = 3.06"

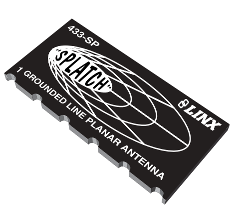
## Specialty Styles

Linx offers a wide variety of specialized antenna styles and variations. Many of these styles utilize helical elements to reduce the overall antenna size while maintaining excellent performance characteristics. A helical antenna's bandwidth is often quite narrow and the antenna can detune in proximity to other objects, so care must be exercised in layout and placement.

## Loop Style



A loop- or trace-style antenna is normally printed directly on a product's PCB. This makes it the most cost-effective of antenna styles. The element can be made self-resonant or externally resonated with discrete components but its actual layout is usually product-specific. Despite its cost advantages, PCB antenna styles are generally inefficient and useful only for short-range applications. Loop-style antennas are also very sensitive to changes in layout or substrate dielectric which can introduce consistency issues into the production process. In addition, printed styles initially are difficult to engineer, requiring the use of expensive equipment including a network analyzer. An improperly designed loop will have a high SWR at the desired frequency which can introduce instability in the RF stages.




Linx offers low-cost planar and chip antennas which mount directly to a product's PCB. These tiny antennas do not require testing and provide excellent performance in light of their compact size. They are an excellent alternative to the often problematic "printed" antenna.

# LEGAL CONSIDERATIONS

NOTE: HP-3 Series modules are intended to allow for full Part-15 compliance; however, they are not approved by the FCC or any other agency worldwide. This is because the module's performance and legality may be affected by external factors specific to a user's application. The purchaser understands that testing and approvals of a finished product may be required prior to the sale or operation of the device, and agrees to utilize the component in keeping with all laws governing their use in the country of operation.

When working with RF, a clear distinction must be made between what is technically possible and what is legally acceptable in the country where operation is intended. Many manufacturers have avoided incorporating RF into their products as a result of uncertainty and even fear of the approval and certification process. Here at Linx our desire is not only to expedite the design process, but also to assist you in achieving a clear idea of what is involved in obtaining the necessary approvals to legally market your completed product.

In the United States the approval process is actually quite straightforward. The regulations governing RF devices and the enforcement of them are the responsibility of the Federal Communications Commission (FCC). The regulations are contained in the Code of Federal Regulations (CFR), Title 47. Title 47 is made up of numerous volumes; however, all regulations applicable to this module are contained in volume 0-19. It is strongly recommended that a copy be obtained from the Government Printing Office in Washington, or from your local government book store. Excerpts of applicable sections are included with Linx evaluation kits or may be obtained from the Linx Technologies web site (www.linxtechnologies.com). In brief, these rules require that any device which intentionally radiates RF energy be approved, that is, tested, for compliance and issued a unique identification number. This is a relatively painless process. Linx offers full EMC pre-compliance testing in our HP/Emco-equipped test center. Final compliance testing is then performed by one of the many independent testing laboratories across the country. Many labs can also provide other certifications the product may require at the same time, such as UL, CLASS A/B, etc. Once your completed product has passed, you will be issued an ID number which is then clearly placed on each product manufactured.

Questions regarding interpretations of the Part 2 and Part-15 rules or measurement procedures used to test intentional radiators, such as the HP-3 modules, for compliance with the Part-15 technical standards, should be addressed to:

Federal Communications Commission
Equipment Authorization Division
Customer Service Branch, MS 1300F2
7435 Oakland Mills Road
Columbia, MD 21046
Tel: (301) 725-1585 / Fax: (301) 344-2050 E-Mail: labinfo@fcc.gov

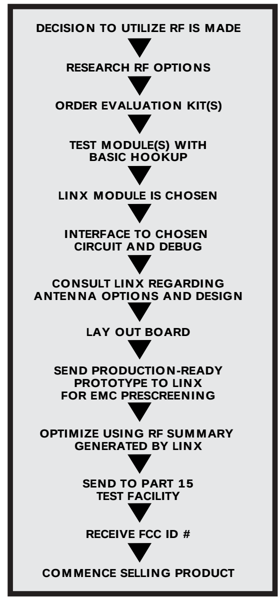
International approvals are slightly more complex, although many modules are designed to allow all international standards to be met. If you are considering the export of your product abroad, you should contact Linx Technologies to determine the specific suitability of the module to your application.

All Linx modules are designed with the approval process in mind and thus much of the frustration that is typically experienced with a discrete design is eliminated. Approval is still dependent on factors such as the choice of antennas, correct use of the frequency selected, and physical layout. While some extra cost and design effort are required to address these issues, the additional usefulness and profitability added to a product by RF makes the effort more than worthwhile.

## SURVIVING AN RF IMPLEMENTATION

The addition of wireless capabilities brings an exciting new dimension to any product. It also means that additional effort and commitment will be needed to bring the product successfully to market. By utilizing an RF module, such as the HP-3, the design and approval process will be greatly simplified. It is still important, however, to have an objective view of the steps necessary to ensure a successful RF integration. Since the capabilities of each customer vary widely it is difficult to recommend one particular design path, but most projects follow steps similar to those shown at the right.

In reviewing this sample design path you may notice that Linx offers a variety of services, such as antenna design, and FCC prequalification, that are unusual for a high-volume component manufacturer. These services, along with an exceptional level of technical support, are offered because we recognize that RF is a complex science requiring the highest caliber of products and support. "Wireless Made Simple" is more than just a motto, it's our commitment. By choosing Linx as your RF partner and taking advantage of the resources we offer, you will not only survive implementing RF, but you may even find the process enjoyable.




**TYPICAL STEPS FOR IMPLEMENTING RF**

## HELPFUL APPLICATION NOTES FROM LINX

It is not the intention of this manual to address in depth many of the issues that should be considered to ensure that the modules function correctly and deliver the maximum possible performance. As you proceed with your design you may wish to obtain one or more of the following application notes, which address in depth key areas of RF design and application of Linx products. These applications notes are available on-line at www.linxtechnologies.com or by contacting the Linx literature department.

| NOTE # | LINX APPLICATION NOTE TITLE |
|---|---|
| 00100 | RF 101: Information for the RF challenged |
| 00126 | Considerations for operation in the 902Mhz to 928Mhz band |
| 00130 | Modulation techniques for low-cost RF data links |
| 00140 | The FCC Road: Part 15 from concept to approval |
| 00150 | Use and design of T-attenuation pads |
| 00155 | Serial loading techniques for the HP-3 Series (PS Versions) |
| 00161 | Considerations for sending data with the HP-3 Series |
| 00500 | Antennas: Design, Application, Performance |

# SERIAL CHANNEL SELECTION TABLE

| CHANNEL | TX FREQUENCY | RX LO | CHANNEL | TX FREQUENCY | RX LO |
|---|---|---|---|---|---|
| 0 | 902.62 | 867.92 | 51 | 915.37 | 880.67 |
| 1 | 902.87 | 868.17 | 52 | 915.62 | 880.92 |
| 2 | 903.12 | 868.42 | 53 | 915.87 | 881.17 |
| 3 | 903.37 | 868.67 | 54 | 916.12 | 881.42 |
| 4 | 903.62 | 868.92 | 55 | 916.37 | 881.67 |
| 5 | 903.87 | 869.17 | 56 | 916.62 | 881.92 |
| 6 | 904.12 | 869.42 | 57 | 916.87 | 882.17 |
| 7 | 904.37 | 869.67 | 58 | 917.12 | 882.42 |
| 8 | 904.62 | 869.92 | 59 | 917.37 | 882.67 |
| 9 | 904.87 | 870.17 | 60 | 917.62 | 882.92 |
| 10 | 905.12 | 870.42 | 61 | 917.87 | 883.17 |
| 11 | 905.37 | 870.67 | 62 | 918.12 | 883.42 |
| 12 | 905.62 | 870.92 | 63 | 918.37 | 883.67 |
| 13 | 905.87 | 871.17 | 64 | 918.62 | 883.92 |
| 14 | 906.12 | 871.42 | 65 | 918.87 | 884.17 |
| 15 | 906.37 | 871.67 | 66 | 919.12 | 884.42 |
| 16 | 906.62 | 871.92 | 67 | 919.37 | 884.67 |
| 17 | 906.87 | 872.17 | 68 | 919.62 | 884.92 |
| 18 | 907.12 | 872.42 | 69 | 919.87 | 885.17 |
| 19 | 907.37 | 872.67 | 70 | 920.12 | 885.42 |
| 20 | 907.62 | 872.92 | 71 | 920.37 | 885.67 |
| 21 | 907.87 | 873.17 | 72 | 920.62 | 885.92 |
| 22 | 908.12 | 873.42 | 73 | 920.87 | 886.17 |
| 23 | 908.37 | 873.67 | 74 | 921.12 | 886.42 |
| 24 | 908.62 | 873.92 | 75 | 921.37 | 886.67 |
| 25 | 908.87 | 874.17 | 76 | 921.62 | 886.92 |
| 26 | 909.12 | 874.42 | 77 | 921.87 | 887.17 |
| 27 | 909.37 | 874.67 | 78 | 922.12 | 887.42 |
| 28 | 909.62 | 874.92 | 79 | 922.37 | 887.67 |
| 29 | 909.87 | 875.17 | 80 | 922.62 | 887.92 |
| 30 | 910.12 | 875.42 | 81 | 922.87 | 888.17 |
| 31 | 910.37 | 875.67 | 82 | 923.12 | 888.42 |
| 32 | 910.62 | 875.92 | 83 | 923.37 | 888.67 |
| 33 | 910.87 | 876.17 | 84 | 923.62 | 888.92 |
| 34 | 911.12 | 876.42 | 85 | 923.87 | 889.17 |
| 35 | 911.37 | 876.67 | 86 | 924.12 | 889.42 |
| 36 | 911.62 | 876.92 | 87 | 924.37 | 889.67 |
| 37 | 911.87 | 877.17 | 88 | 924.62 | 889.92 |
| 38 | 912.12 | 877.42 | 89 | 924.87 | 890.17 |
| 39 | 912.37 | 877.67 | 90 | 925.12 | 890.42 |
| 40 | 912.62 | 877.92 | 91 | 925.37 | 890.67 |
| 41 | 912.87 | 878.17 | 92 | 925.62 | 890.92 |
| 42 | 913.12 | 878.42 | 93 | 925.87 | 891.17 |
| 43 | 913.37 | 878.67 | 94 | 926.12 | 891.42 |
| 44 | 913.62 | 878.92 | 95 | 926.37 | 891.67 |
| 45 | 913.87 | 879.17 | 96 | 926.62 | 891.92 |
| 46 | 914.12 | 879.42 | 97 | 926.87 | 892.17 |
| 47 | 914.37 | 879.67 | 98 | 927.12 | 892.42 |
| 48 | 914.62 | 879.92 | 99 | 927.37 | 892.67 |
| 49 | 914.87 | 880.17 | 100 | 927.62 | 892.92 |
| 50* | 915.12 | 880.42 | | | |

**This channel is not counted as it is the Serial Mode default channel (see page 11)*

## MISMATCH CONVERSION TABLE

| VSWR | Insertion Loss (dB) | Power Transmitted (%) | Power Reflected (%) |
|---|---|---|---|
| 17.391 | -6.87 | 20.57% | 79.43% |
| 11.610 | -5.35 | 29.21% | 70.79% |
| 8.724 | -4.33 | 36.90% | 63.10% |
| 6.997 | -3.59 | 43.77% | 56.23% |
| 5.848 | -3.02 | 49.88% | 50.12% |
| 5.030 | -2.57 | 55.33% | 44.67% |
| 4.419 | -2.20 | 60.19% | 39.81% |
| 3.946 | -1.90 | 64.52% | 35.48% |
| 3.570 | -1.65 | 68.38% | 31.62% |
| 3.010 | -1.26 | 74.88% | 25.12% |
| 2.615 | -0.97 | 80.05% | 19.95% |
| 2.323 | -0.75 | 84.15% | 15.85% |
| 2.100 | -0.58 | 87.41% | 12.59% |
| 1.925 | -0.46 | 90.00% | 10.00% |
| 1.433 | -0.14 | 96.84% | 3.16% |
| 1.222 | -0.04 | 99.00% | 1.00% |
| 1.119 | -0.01 | 99.68% | 0.32% |
| 1.065 | 0.00 | 99.90% | 0.10% |
| 1.034 | 0.00 | 99.97% | 0.03% |
| 1.020 | 0.00 | 99.99% | 0.01% |

## NOTES:

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