1.1 RFID Card and Card Reader Description

The HID tag reader (herein know as 'Reader') generates a 125KHz AC magnetic field with the use of a magnet wire coil (referred to as an "exciter"), located inside the reader enclosure. The coil is connected to a 125KHz square wave signal source through a capacitor. The coil/capacitor combination is designed to form a series resonant network that is tuned to 125KHz. The resonance of the coil/capacitor network turns the square wave drive signal into a sine wave AC current. The magnetic AC field produced by the current in the coil propagates into space and is intercepted by the remote RFID tag (cards and fobs), several inches from the coil. Another coil inside the RFID tag collects some the intercepted magnetic field and converts it into a 125KHz AC voltage. A capacitor connected in parallel with the coil forms a parallel resonant circuit. The parallel resonant circuit improves the coil's efficiency in converting the AC magnetic field into a voltage. The voltage across the tag coil is routed to a RFID microchip, also inside the tag. The analog front-end of the RFID chip converts the majority of the energy from the AC voltage produced by the tag coil into a DC voltage that is used to supply power to the microchip. In addition, the 125KHz AC voltage is used by the microchip to form a digital clock signal. The microchip uses the clock signal to produce a serial data message from a non-volatile memory, within the microchip. The digital message signal controls an electronic switch that connects and disconnects a resistor to the tag coil. The resistor forms a load across the RFID tag coil and causes the AC voltage across the coil to be reduced. As the digital message emerges from the RFID microchip and switches the resistor across the coil, the AC voltage waveform across the RFID coil is amplitude modulated or frequency modulated. When the tag is placed in front of the Reader, some of the modulated signal from the RFID tag is coupled to the Reader's coil and appears as weak amplitude modulated signal. As the tag is moved closer to the Reader coil, the level of modulation seen across the Reader coil increases. The modulated voltage across the Reader's coil is processed by the Reader's electronic circuit and is ultimately shaped into the original digital message that emerged from the tag's RFID microchip.

The laws of physics dictate that the strength of the magnetic field projected outward from an open coil will decrease according an inverted cube relationship. In other words, if the separation distance between a tag and a Reader is increased by a factor of two, the magnetic field strength will decrease by a factor of eight. To maintain the same signal level at the RFID tag, the current in the Reader's coil would then have to be increased by a factor of eight. At a given desired tag read distance, the Reader's excitation magnetic field needs to be strong enough to activate the RFID tag. The Reader's receiver circuit also has to be sensitive enough to detect the weak signal produced by the distant RFID tag. If the tag's circuit is being fully activated by the Reader's magnetic field but the Reader is not able to detect the tag's return signal, the system is said to be "receive limited". The tag would then have to be moved closer to the Reader to be read, shortening the read distance. In other cases the Reader's receiver circuit may be sensitive enough, but the magnetic field produced by the Reader is insufficient to excite the tag. Such systems are said to be "exciter limited". Again, the tag would have to be moved closer to the Reader to be read. The goal in a properly designed RFID system is to generate a sufficient magnetic field to insure a tag will be excited at a specific distance and to have a receiver circuit sensitive enough to insure the tag's return signal could be detected at that same distance.

1.2 125KHz Receiver Information

The standard HID FSK RFID card's modulated signal is composed of two separate frequencies. The digital message causes the modulation frequency to shift between 12.5KHz and 15.625KHz. The rate, at which the data information is sent, is around 1250 BPS. The minimum number of modulation frequency cycles per bit cell is about 7.

The receiver section of an RFID reader must convert sideband FSK frequencies to baseband frequencies for proper processing. Issues pertinent to RFID readers are briefly discussed below.

1.2.1 Baseband Frequencies, FSK Cards

- Two modulation frequencies = 12.5KHz (125KHz ÷ 10) and 15.625KHz (125KHz ÷ 8)
- Difference between two frequencies = 3.125KHz.
- Center between two modulation frequencies = 14KHz.
- Maximum practical baseband band-pass filter Q = 4.5.

1.2.2 Lower Sideband Frequencies, FSK Cards

- The two tag modulation frequencies produce two lower sidebands -- F1 = 109.37KHz / F2 = 112.5KHz
- Difference between two sideband frequencies = 3.15KHz.
- Center frequency between two sidebands = 111KHz
- Maximum practical 111KHz sideband band-pass filter Q = 37

1.2.3 FSK Band-pass Filters

If a band-pass filter were used with a 111KHz-center frequency, its bandwidth should not be less than ±1.5KHz and should have a Q less than 37. A Q greater than 37 would begin to attenuate the two sideband frequencies. However, if non-adjustable and therefore less accurate components were used, a more practical bandwidth would be about ±2.5KHz with a Q of about 20. With a Q of 20, a bandpass filter centered at 111KHz, would attenuate the 125KHz-carrier signal by about 14db (÷5).

1.2.4 125KHz Notch Filters

A high Q 125KHz-notch filter could be used without influencing the sideband frequencies. For example, a 125KHz notch filter with a Q of 40 would provide about 20db (÷10) of 125KHz attenuation without altering the sidebands. If three accurate pre-tuned Q=40 passive 125KHz notch filters were used, before any active stages, a total of 60db (÷1000) of 125KHz attenuation could be achieved. To receive both FSK and AM modulation frequencies, the notch filters should not contain any additional frequency selection networks. Notch filters using toroidal or potcore style inductors have been built with higher Qs and have tested to provide up to 90db of 125KHz filtering action. However, such filters would require manual adjustments. Notch filters designed to be connected directly across the 125KHz exciter coil will need to be able to handle voltages in excess of 250v peak to peak and will need to have high input impedance.

1.2.5 Receiver Techniques

A popular demodulation technique for receivers in RFID readers is referred as envelope detection and consists of diode detector. The main advantage of the diode detector technique is that the frequency of the signals of interest are three octaves removed from the 125KHz carrier frequency instead of only 10% removed, as in the sideband receiver approach (no demodulation is used). The receiver filter circuits would therefore be easier to achieve high gain as well as high selectivity without the use of expensive manually adjustable networks.

The signals observed across the exciter coil, would be a small card return signal that is superimposed on a very strong 125KHz signal. The exciter coil voltage could be in excess of 250v peak to peak. A single diode detector network would be used to convert the upper and lower sideband RFID card signals into baseband signals. The signal following the diode detector would be a 125v DC level containing the very weak 15.65KHz and 12.5KHz baseband signals of interest and some 125KHz carrier signal. The rather high voltages produced by the diode detection technique do need to be considered when selecting the circuit components. Also, any filters following the diode detector will need to have high impedance, to prevent them from loading down the exciter signal. 125KHz carrier on/off duty cycle control schemes, often used to reduce the average 125KHz power levels, also need to be considered. Each time the 125KHz carrier is turned on or off a 125v level shift would occur. The on and off exciter carrier switching produce very strong low frequency components that would need be removed before the signal was fed to any active filters. Fortunately, the duty cycle frequency is often only about 10Hz and could therefore be easily filtered with some passive components

The low pass filters that form the diode detector circuit would need to be designed carefully. To prevent the circuit from loading down the exciter signal across the coil, the filters will need to use high value resistors and low value capacitors. For an exciter coil voltage of about 250v peak to peak, the filter resistors should be greater than 400KΩ. A three pole passive low pass filter with a knee set at 16KHz and a slope of 18db per octave would attenuate the 125KHz-carrier signal by a factor of 54db (÷500). With such a filter, the rectified 125KHz 125v peak to peak signal would be reduced to about 0.25v peak to peak. However, if the RFID card signal were only about 100µV peak to peak, the ratio between the signals of interest and the 125KHz noise would still be about 68db. Additional filter and gain stages would be needed to produce useful RFID card signal amplitude. If we assume a minimum processed signal level of 50mV peak to peak, then an overall circuit gain of 500 would be needed. If the front-end low pass filter was connected to three bandpass filter stages with a Q of 4 and an overall gain of 1000 the 100µV RFID card signal would be increased to 0.1 volts and the 125KHz carrier would be reduced to nearly nothing.

1.2.6 Exciter Coil Considerations

The card reader exciter coil is designed to generate an AC magnetic field. The magnet field is proportional to the AC current in the coil and the number of turns in the coil. To achieve a practical efficiency, a capacitor is placed between the coil and the coil drive signal. The coil and capacitor form a series resonant circuit. At the resonant frequency, the impedance of the coil/capacitor network drops to a low level. Only the AC resistance of the network limits the coil current. The dominant source of the AC resistance is the DC resistance of the magnet wire used in the coil. The coil wire needs to be selected carefully to achieve the desired coil inductance and the desired coil resistance. If the coil resistance is too low the drive current will be higher than desired. The coil diameter and wire gauge also need to be picked, based on the space available inside the card reader.

To collect as much tag return signal as possible, the exciter coil should have as many turns as possible. However, to maximize the magnetic field produced, the coil may need to have fewer turns. A compromise must therefore be reached between these two exciter coil needs. For a given peak to peak drive signal applied to the exciter coil, there is large family of possible coil/capacitor combinations that will resonate at 125KHz. But, the goal is to have a coil with the highest practical Q and the right resistance to limit the drive current. By carefully selecting the magnet wire size such a goal can be achieved.

The coil's Q is determined by the ratio of its inductive reactance and its series AC resistance. A high Q will insure that frequencies higher than 125KHz will be attenuated. However, if the exciter coil is to also serve as a receiver for the tag's return signal, the maximum practical Q should be less than about 40. Qs higher than 40 will cause the upper and lower sidebands of the tag signal to be attenuated. These two needs conflict with each other.

If a design calls for a series AC resistance of 15Ω, the inductive reactance of the coil will therefore need to be less than 600Ω to insure the Q is less than 40. A coil with an inductance of 750µH has about the right reactance.

If the coil network is to be driven from lower peak to peak voltages, the coil design will need to change to maintain the same magnetic field. In other words, the amp-turns will need to be the same if the unit is to excite the distant tag properly. The easiest way to achieve the voltage transformation is with the use of a transformer. The lower peak to peak voltage would be connected to the primary of the transformer while the exciter coil would be connected to the transformer secondary