by **Tom Tang** | Lear Corporation

RKE – OPENING MORE THAN DOORS

The history of remote keyless entry (RKE) products has been characterized by the increase of range performance from a few meters back in the 1980s to a few hundred meters today. The key milestones of RKE product history can be summarized as follows: radio frequency technology replacing the infrared technology (1980s), VHF/UHF band replacing the 27 MHz civil band (1990s), and the superheterodyne receiver replacing super-regenerative receiver (2000s). Now, RKE engineers face a new challenge, namely to overcome the range limitation of today's RKE technology. Is it possible to achieve more than 500 meters of range as contrasted to today's technology?

Figure 1. Lear's CAR2U fob.

More than 20 years ago, when the first radio frequency (RF) RKE system was developed, consumers were pleased to have 10 meters of operating range after experiencing the poor range performance of infrared systems. For a long time, consumers have been satisfied with RKE systems with a 10-meter to 20-meter range. However, in 2004, GM launched Malibu with an OEM-installed remote start system designed by Lear Corporation to provide more than 60 meters of range at all angles using an internal antenna. In 2005, GM and Lear launched a 150-meter RKE system to support the remote start feature. Today, OEMs are looking for an RKE system with a range as far as 500 meters or more. In such a non-line-of-sight system, traditional feedback such as horn or light flash is not helpful. The consumer needs a new way to verify the result of the RKE transmitter operation such as remote start. Lear Corporation announced in 2004 that a two-way RKE system is available to consumers (CAR2U system, Figure1). Figure2 is a plot showing the range of a Lear RKE system tested in a vehicle.

RKE SYSTEM LINK BUDGET

While the characteristics of wave propagation and noise are of interest to those in receiver design, we are more interested in how these characteristics affect RKE system design. Figure 3 is a block diagram of a communication link that allows the information transfer between a source, where the information is generated, and a destination that requires it. An RKE system is often referred to as a simplex system where a single source transmits to a single destination. The Lear CAR2U is a half-duplex system where two links are used, but only one transmitter may transmit at a time. The following formula is used to describe the power budget of an RKE link:

Received Power = transmitted power Pt + Tx antenna Gain Gt – transmission loss L – VF + Rx antenna Gain Gr - Margin (5-10 dB)

Eq. 1

where Rx is receiver, Tx is transmitter, VF is vehicle factor.

The propagation loss from an RKE transmitter antenna to a receiver antenna is influenced by many effects including ground reflection, refraction and absorption by the environment, diffraction by an obstacle (terrain effect) and fading. Free space loss, as an ideal case, can be normally used to characterize propagation of an RF link. This is defined as the loss between two isotropic antennas in free space with no ground or air. Although this is a hypothetical case that can't be realized physically, it is a useful concept for calculations because the gain of practical antennas is commonly referenced to the isotropic antenna.

In typical RKE systems, the electromagnetic energy is emitted by a transmitter antenna with a typical gain of -10 dBi to -20 dBi. It must be noted that the effective transmitter output power is FCC regulated. This energy is attenuated along the distance d and then through the vehicle body (shadow loss or vehicle factor) to the receiver antenna whose gain is typically from -20 dB to +2 dBi. Finally, the signal reaches the RKE receiver. The free space propagation loss L is expressed according to the inverse square law. Mathematically, the loss is written as:

$$L = 20\log\left(\frac{\lambda}{4\pi d}\right)$$

Eq. 2

Where λ is the wavelength and d is distance from transmitter antenna to receiver antenna. The free space propagation loss is independent from the wavelength or frequency, and the

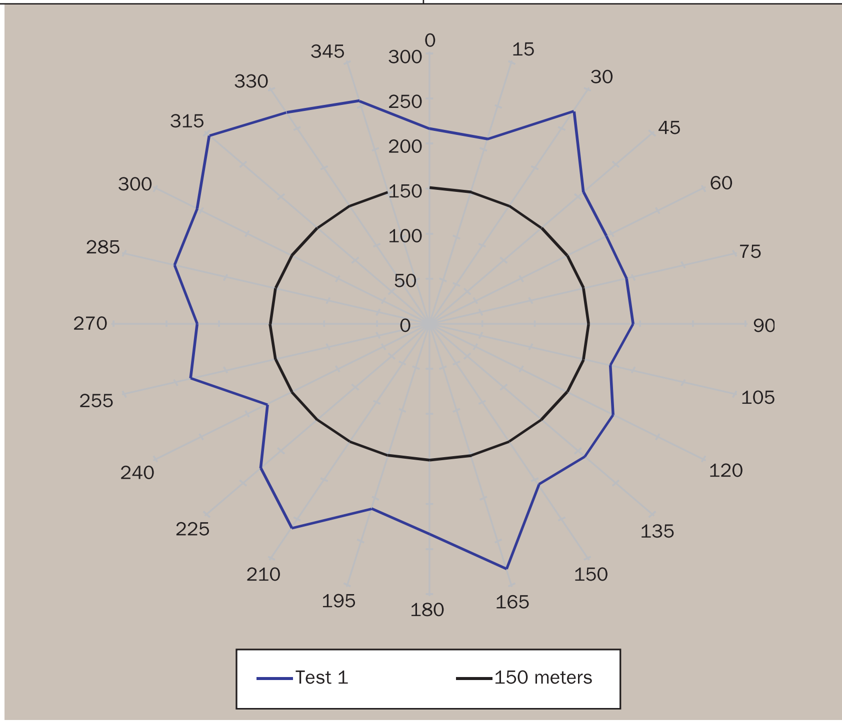

Figure 2. An RKE range plot from a Lear RKE system.

frequency is associated with the receiver antenna aperture that can be addressed by receiver antenna design. After considering the ground effect, the loss can then be written as:

$$L = 20\log\left(\frac{\lambda}{4\pi d}\right) + 20\log\left(2\sin\left(\frac{2\pi h_r h_t}{\lambda d}\right)\right)$$

Eq. 3

Figure 4 shows a plot of propagation loss vs. distance. This loss degrades the far range performance with the inverse d^4 law by more than 25 dB (at 500 meters or more) compared to free space propagation. Equation 3 is based on a perfect ground surface; our simulation shows that the real-world ground makes the attenuation go either way. This is why RF engineers often experience variation of range performance at far distances, which also explains why sometimes a 'hole' is observed in the range test.

FCC regulates maximum peak power (or electrical field strength) at 95.6dBμV/m at three meters, which is equivalent to 0.3dBm EIRP (equivalent isotropic radiation power) power for an intentional transmitter. This is the maximum allowed power from a 315 MHz RKE transmitter. Most of today's RKE transmitters are working at -10 dBm level due to reasons of transmitting protocol, cost, as well as harmonic control. However, engineers can control the antenna directivity, polarization, as well as the quality of the transmitted signal to provide the optimum transmission to the receiver. If the vehicle factor is 5 dB, margin is 5 dB, transmitter output power is 0.3 dBm, and range is 500 meters, equation 1 can be written as:

Received power = 0.3dBm – 108.3 – 5 + Gr - 5

Eq. 4

An internal receiver antenna typically has a negative gain Gr of around -10 dBi to -20 dBi, and an external antenna may have gain from -10 dBi to 2 dBi. For a system range of 500 meters, assuming that a -5 dBi gain external antenna is used, the receiver sensitivity would be

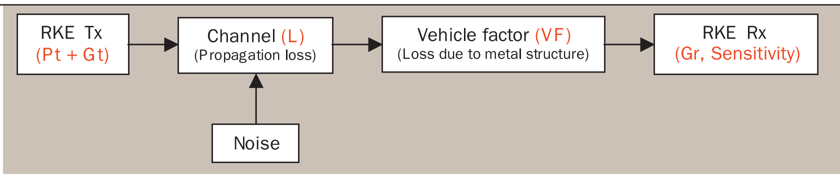

Figure 3. Communication link and power budget.

Received power = -123dBm.

Eq. 5

One thing must be mentioned here: to achieve a receiver antenna with a -5 dBi gain using an external antenna is not an easy task. This would have to be a well-designed antenna. In the RKE industry, RKE antenna design has been mishandled in the past where, in many cases, a poorly designed antenna was used for RKE applications. Most of the time, the RKE range performance is degraded by using a poorly designed external antenna compared to a well-designed internal antenna, especially in a noisy environment. The antenna design and packaging are important to the RKE range performance, which could impact the RKE system link by ±10 dB to ± 20 dB. Diversity antennas may also be used to improve the gain either by spatial or spectral diversity.

In Japan, low-power devices like RKE transmitters can only transmit a quasi-peak power at 54 dBμv/m at three meters, which is 40 dB lower than the power allowed in North America. This has been a problem for those companies that abide by the regulations. Present RKE systems for the Japanese market achieve less than five meters of range, even with a high-quality antenna. When the range d is much smaller than 5*ht*hr (where ht and hr are the heights of transmitter and receiver antenna respectively), equation 3 is no longer valid. Figure 6 shows the propagation loss vs. distance. In the range of less than 10 meters, the propagation loss varies by more than 20 dB due to ground reflection. That is in part due to the unpredictability of range tests in Japan. Using 65 dB for propagation loss at 20 meters, -42 dBm EIRP power for the transmitter output power, -5 dBi for receiver antenna gain, 5 dB for vehicle factor, and 5 dB for system margin, the receiver sensitivity would have to be at least -122 dBm to meet the 20-meter range requirement in Japan.

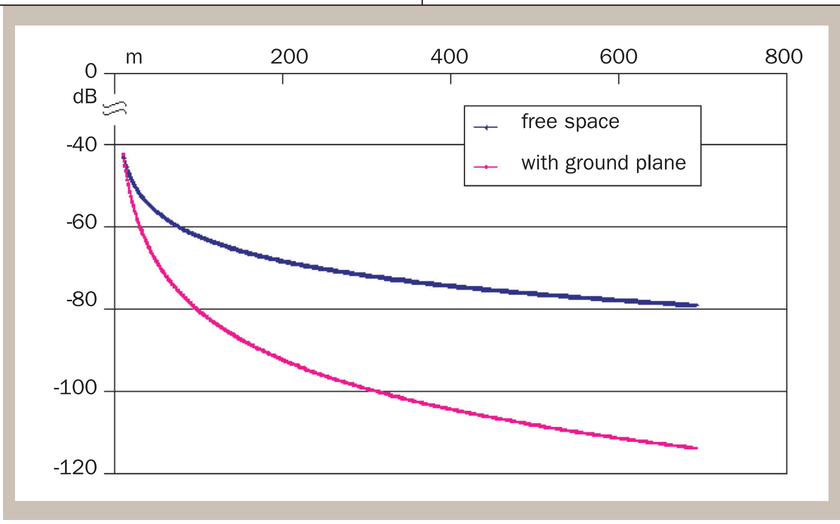

Figure 4. Wave propagation loss vs. distance.

VEHICLE FACTOR AND RECEIVER ANTENNA GAIN

Almost every RKE system in the market today uses the UHF band. The most popular frequency for the North American market is 315 MHz, while most European countries selected the 434 MHz and 868 MHz. The transmission characteristics of the above bands are intended to be line-of-sight. The signal in this band tends to be strong and stable as long as a good and clear line of sight with adequate ground clearance exists between the two elevated transmitter and receiver antennas. However, as the wavelength becomes sufficiently small, the reflected, scattered, diffracted and refracted waves also play an important role in the signal transmission. In most RKE applications, the receiver and transmitter are not in line-of-sight, and the communication link is completed through multiple paths such as scattered and reflected multipaths. Figure 7 is a simulation result of wave propagation from an RKE transmitter to a vehicle. The red color represents stronger field strength while the blue represents a weak spot. In general, the field at the upper instrument panel, seat headrest and overhead area is more intense (shown in red) representing a vehicle factor from 5 dB to 10 dB at 315 MHz. These are the locations where the receiver antenna should be placed. You may have noticed that under the vehicle may offer a good location for reception also. It should be noted that vehicle factor and antenna gain can be traded off against one another to achieve a suitable design.

The vehicle factor (VF) is the attenuation caused by the vehicle structure. VF can range from a few decibels to 30 dB. VF is a key element of the link budget analysis for RKE system design, but it is not normally available to the designer during the engineering development phase. Lear

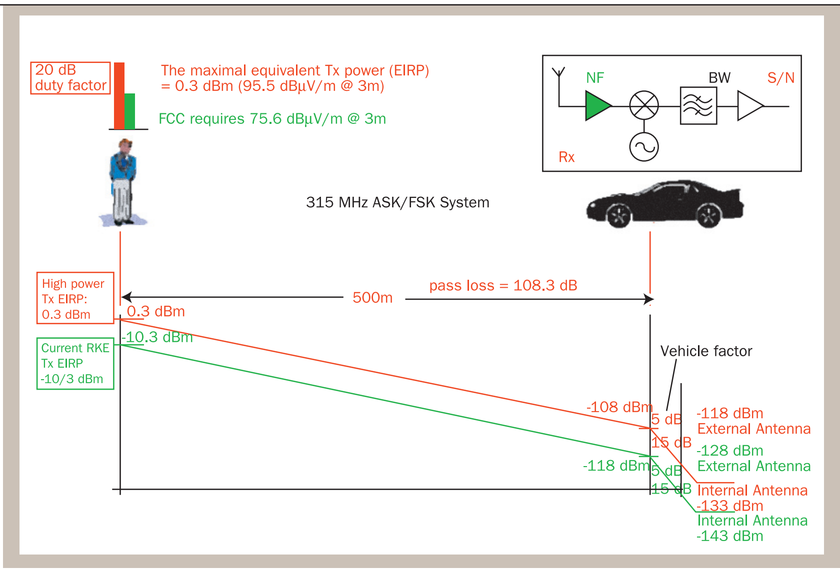

Figure 5. Gain or loss in an RKE link.

engineers developed a method using a simulation tool with test methods to estimate the vehicle factor. Using this method, we find that VF is sensitive to vehicle structure, location of receiver antenna, and nearby metal structure. VF can also dictate the minimum distance that an antenna can be placed away from a metal or vehicle structure. The above sets of parameters constitute key design data to a RF system engineer and should be part of the RKE system and antenna engineering process for optimizing the system and antenna performance.

Many methods have been used to reduce vehicle factor. As an example, location of a receiver antenna may improve the RKE link budget by 10 dB to 20 dB. Receiver antenna is optimally placed at a minimum distance away from the vehicle metallic structure. This distance ranges from a few millimeters to a few centimeters depending on the size and orientation of the antenna and the properties of the structure material. Our studies show that the attenuation may increase at a slope of 1/R4 in the region close to the vehicle metal structure. R is the distance to the measurement point. Using a more optimum frequency is often proposed for range improvement. Electromagnetic waves having frequencies up to 1 GHz behave in a similar way to 315 MHz regarding the propagation characteristics, but at higher frequencies or smaller wavelengths it is also possible to use antenna diversity in a relatively small vehicle. Higher frequencies may offer vehicle factor improvement through using multiple antennas when line-of-sight paths present difficulty. Although using higher frequencies may lead to better antenna design and higher transmitted power (due to FCC regulations), the challenges to RF engineers may be altered when a higher frequency is adopted for RKE applications. Cost and power consumption may become bigger challenges to RF engineers.

RKE RECEIVER DESIGN

The minimum detectable signal, or sensitivity, is the starting point of receiver design. Sensitivity is limited by constraints created by the fundamental laws of physics and state-of the-art of technology. Noise sets the sensitivity limit for a receiver; ideally, we can have -174 dBm max sensitivity if the receiver has a 0 dB NF and 0 dB signal-to-noise ratio, and 1Hz bandwidth. However, a practical RKE receiver is far from having these ideal parameters. Normally, the dominant noise affecting the RKE receiver performance also includes narrowband noise such as onboard clock noise and ambient in-band noise. These sources of

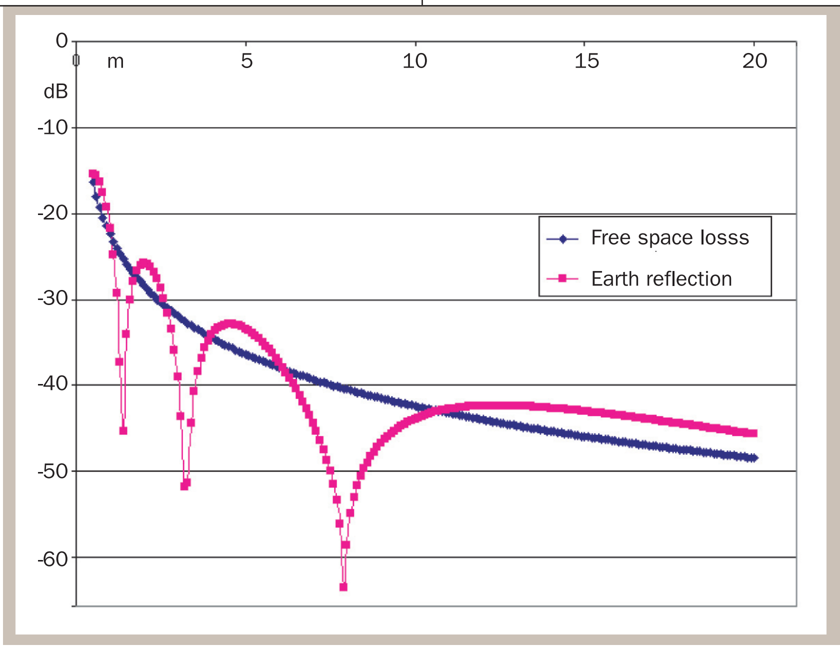

Figure 6. Short-range loss vs. distance.

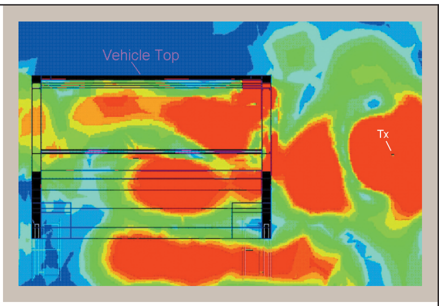

Figure 7. 315 MHz wave propagation from a RKE fob to a vehicle.

noise may degrade the signal-to-noise ratio or the sensitivity. High sensitivity receivers may require better dynamic range control, which may require the use of angular modulation rather than amplitude modulation. RKE receiver sensitivity is influenced by receiver bandwidth. RKE receiver sensitivity is expressed by the equation below:

Receiver sensitivity = -174 + 10log BW + S/N (dB) + NF (dB)

Eq. 6

where BW is the receiver bandwidth, S/N is receiver signal-to-noise ratio, and NF represents the receiver noise figure. Antenna noise is not included. The inclusion of the antenna would degrade the system noise figure according to the following expression:

NFActual = 1+ (NF-1)To/Ts

Eq. 7

where To is 290˚K and Ts is the antenna temperature. For most RKE applications, the superheterodyne receiver has been dominant. The superheterodyne receiver makes use of the principle of mixing an incoming signal with one generated by a local oscillator (LO) in a non-linear device. The superheterodyne receiver uses a LO frequency offset by a fixed intermediate frequency (IF) from the desired signal. The signal-to-noise ratio from ASK and FSK demodulator may be represented by Figure 8.

The current RKE receiver operates at a signal-to-noise ratio of about 12 dB, at which the bit error rate BER is about 10-2. If a proper protocol is applied together with a good decoding strategy, the S/N may be lower than 10 dB at the same BER. An 8 dB receiver noise figure is popular for present RKE receivers. This will give us receiver sensitivity at -156 dBm + 10log BW. If the receiver bandwidth is 30 kHz, the receiver would have a sensitivity of about -111 dBm. According to equation 5, 12 dB more receiver sensitivity may be needed to implement an RKE system with 500 meters of range. Other factors may degrade RKE system performance more such as receiver noise figure variation over temperature, transmitter power or receiver sensitivity variation.

What methods are available to improve the link budget so that a 500-meter RKE system is viable? A better demodulator can offer 3 dB to 5 dB improvement to the signal-to-noise ratio. Reducing the receiver NF can be key to improving the system budget; nevertheless, bandwidth is limited by data rate and RF oscillator stability. It is possible to achieve 2 dB to 5 dB by using a better encoding, error correction strategy, and special receiver software algorithms. The scanning receiver has been used in RKE systems to improve receiver performance in the presence of in-band jamming. Often, the jamming signals are emissions from other low-power applications. This is a cost-effective way to implement the narrowband receiver. However, given the same receiver bandwidth for scanning and fixed receivers, the overall receiver sensitivity is not improved due to lack of system NF improvement. A higher-frequency band may be a good choice to achieve more than 500 meters of range. The FCC allows the use of higher output power at 900 MHz, 2.4 GHz or higher bands as long as a bandwidth requirement is met. Aside from power consumption and cost issues, engineers will probably have to face jamming issues from numerous high-power applications operating at close frequencies.

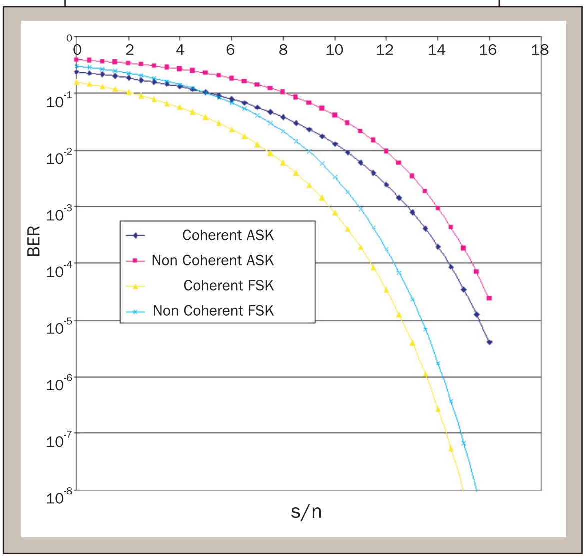

Figure 8. Signal to noise ratio vs. BER.

CONCLUSION

These are just few of the technical problems that must be investigated and resolved to have RKE systems provide the functionality that carmakers and their customers expect. To exceed 500 meters, severe challenges exist. As a leader in this area, Lear will continue to investigate and develop solutions that provide value to the driving experience.

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