Appendix A – *Question 7: Purpose of Experiment*

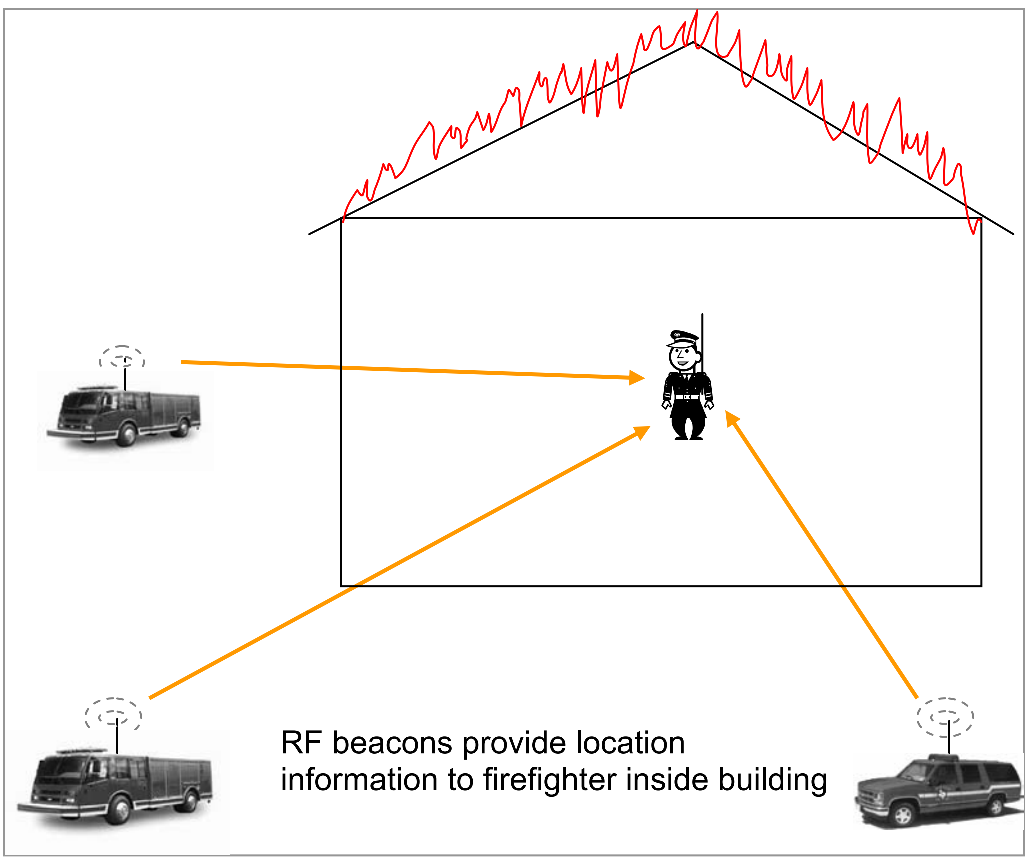
Attach as a text document …

a) Complete program of research and experimentation with equipment description and theory of operation

This experimental license will be used to research a technique for tracking and locating high value assets. The initial market application will be in the public safety and homeland security markets tracking firefighters and rescuers.

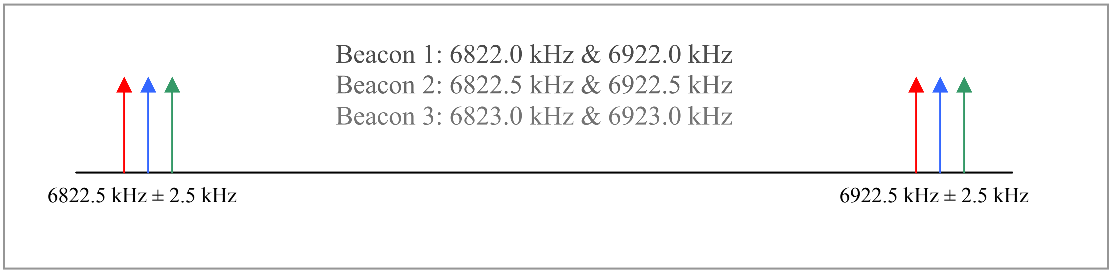
Every year firefighters die in house fires because they have lost their sense of direction, usually due to thick, black, smoke and can not find their way out of the building. Providing a means for a firefighter to track his/her location within a building would safe lives.

A typical deployment would be a building fire where RF beacons (transmitters) are placed about the building.



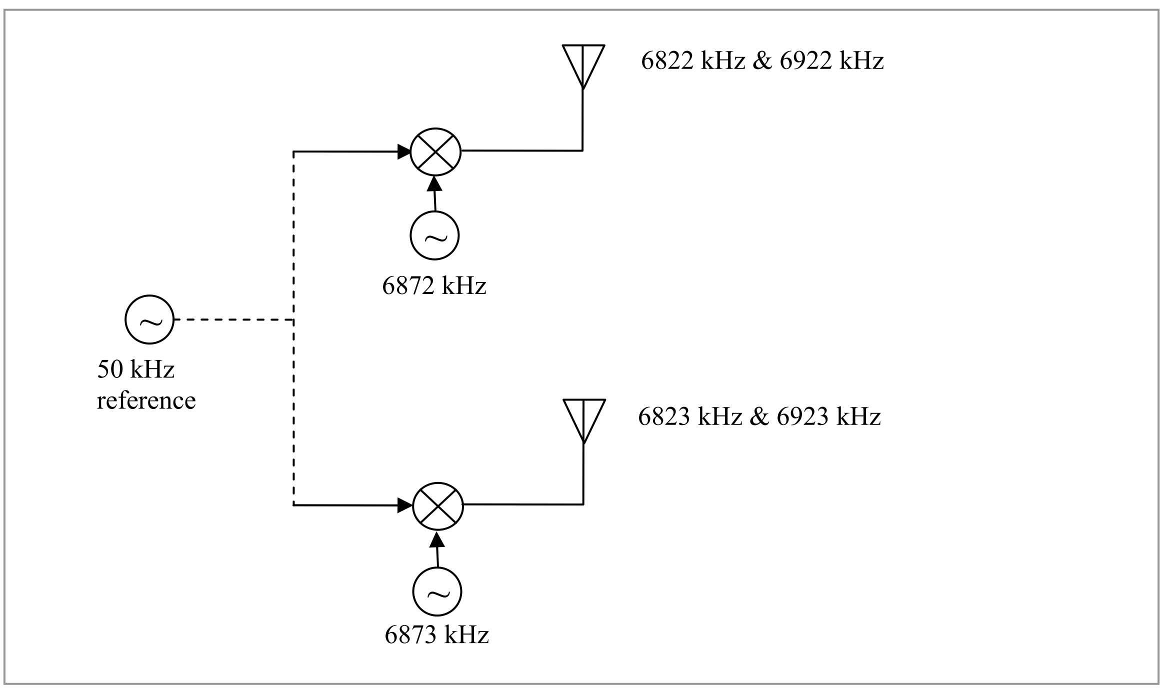
A firefighter would carry a small device, about the size of a transistor radio, into the burning building. This small radio device would do signal processing on the RF beacon transmissions, which would provide the user with information as to their location with respect to the beacon locations.

The technique uses dual frequency tone beacons to determine differential phase that can be translated into time difference of arrival based tracking and location. In the above cartoon, each fire vehicle contains an RF beacon and each RF beacon transmits two RF tones. The two tones are spaced 100 KHz apart and each beacon is slightly offset in frequency from its neighbor. We can represent the resulting spectrum, in this case three beacons, as shown below.



To see how this technique works, we select two beacon signals to work an illustrative example.

As previously stated, each beacon generates two RF tones separated in frequency by 100 KHz. These two tones are actually generated as double sideband, suppressed carrier modulation from a reference 50 KHz signal generator. This 50 KHz reference is supplied to all the beacon stations. For our two beacon example, the tone pairs can be generated as shown below. Note: this is not exclusively the only way to generate the tone pair.



For our example, a receiver receives the RF tone pairs (a total of four RF tones for this example) and individually filters out each RF tone via a bank of bandpass filters.

This is most readily done in the digital signal processing domain via the Fast Fourier Transform (FFT). DSP processing is done to extract the time difference of arrival information. We now show the mathematics behind this DSP processing.

Let the reference RF frequency be given as ω_R.
Let the first beacon have a center frequency of ω_1.
Let the second beacon have a center frequency of ω_2.

First Received Beacon Signal:
$S_1 = A_1\{\cos[(\omega_1 + \omega_R)\cdot(t+\tau_1)] + \cos[(\omega_1 - \omega_R)\cdot(t+\tau_1)]\}$

Second Received Beacon Signal:
$S_2 = A_2\{\cos[(\omega_2 + \omega_R)\cdot(t+\tau_2)] + \cos[(\omega_2 - \omega_R)\cdot(t+\tau_2)]\}$

where A_1 is the path loss between beacon 1 and the mobile receiver
A_2 is the path loss between beacon 2 and the mobile receiver
τ_1 is the propagation time between beacon 1 and the mobile receiver
τ_2 is the propagation time between beacon 2 and the mobile receiver

We can write any cosine signal as a sum of exponentials using the identity $\cos x = \frac{1}{2}\left(e^{jx} + e^{-jx}\right)$. We apply this identity to the received signal S_1 and S_2 and keep only the positive frequency terms (something which is readily done in the DSP domain). We thus get

$$S_1' = \frac{A_1}{2}\left\{e^{j(\omega_1+\omega_R)\cdot(t+\tau_1)} + e^{j(\omega_1-\omega_R)\cdot(t+\tau_1)}\right\}$$

$$S_2' = \frac{A_2}{2}\left\{e^{j(\omega_2+\omega_R)\cdot(t+\tau_2)} + e^{j(\omega_2-\omega_R)\cdot(t+\tau_2)}\right\}$$

For each of these signals we form a new signal by multiplying the upper sideband signal by the conjugate of the lower sideband signal.

$$\mathrm{K}_1 = \frac{A_1}{2}e^{j(\omega_1+\omega_R)\cdot(t+\tau_1)}\cdot e^{-j(\omega_1-\omega_R)\cdot(t+\tau_1)} = \frac{A_1}{2}e^{j2\omega_R(t+\tau_1)}$$

$$\mathrm{K}_2 = \frac{A_2}{2}e^{j(\omega_2+\omega_R)\cdot(t+\tau_2)}\cdot e^{-j(\omega_2-\omega_R)\cdot(t+\tau_2)} = \frac{A_2}{2}e^{j2\omega_R(t+\tau_2)}$$

We now for the product

$$\mathrm{K}_2\cdot\mathrm{K}_1^* = \frac{A_2}{2}e^{j2\omega_R(t+\tau_2)}\cdot\frac{A_1}{2}e^{-j2\omega_R(t+\tau_1)} = \frac{A_2\cdot A_1}{4}e^{j2\omega_R(\tau_2-\tau_1)} = \frac{A_2\cdot A_1}{4}e^{j\phi}$$

Extracting the phase term we have that

$$\left(\tau_2 - \tau_1\right) = \frac{\phi}{2\omega_R}$$

Thus, we have extracted the time difference of arrival from the dual tone beacon transmissions. This is an important parameter that allows us to do tracking and location. A paper that discusses the time difference of arrival algorithm can be found on the web at http://grouper.ieee.org/groups/802/15/pub/04/15-04-0572-00-004a-tdoa-localization-techniques.ppt

We have selected an operating frequency of just under 7 MHz for technical reasons. In theory we'd like to operate at as low a frequency as possible. The constraints are adequate antenna bandwidth (we'll be using modified 40 meter amateur radio mobile antennas) and reasonable antenna efficiency. Our antenna vendor has indicated he can get just over 100 KHz of bandwidth at 6.8725 MHz. Also, the antenna efficiency is about 40%. Going lower in frequency would give us better building penetration but at the cost of lower antenna efficiency and excessively narrow antenna bandwidth.

We've picked the 6765 kHz to 7000 kHz band based on observing the on-the-air potential interference. This band is licensed for fixed and mobile services in the US. There are two licensed international shortwave broadcasters in this band. These are

WYFR: 100 kW @ 6855 kHz
WWFV: 50 kW @ 6890 kHz

We've not yet noticed any other licensed users in this band. Our dual frequency bands of 6822.5 kHz and 6922.5 kHz are 30 kHz removed from these international SW broadcasters. We do not anticipate that we'll either cause interference to these stations nor will we experience interference from these stations.

Even through our beacon transmitters are somewhat dispersed in location, they are all within 100 meters of each other. There are 3 transmitters and each transmitter will have an ERP not to exceed 20 watts. The total radiated power from the location will not exceed 60 watts and this radiated power will be divided between the lower frequency cluster and the upper frequency cluster (30 watts each).

Our equipment will have a Morse code ID capability and we'll periodically ID our experimental station via slow speed on-off keying Morse code.

b) Specific Objectives and Accomplishments

An obvious question is how well does this technique work in actual buildings? The experimental license will allow us to test the performance of this technique in different building types. We are asking for sufficient transmitter power so as to assure we have enough SNR inside a building to be able to conduct our testing. Most likely the actual product would be working at reduced transmit power levels. Our specific objective will be ascertaining our position in a building using the dual tone technique against our surveyed position.

c) Program promise of contribution to radio art

There have been several attempts over the last few years by various companies to use low frequency radio beacons for tracking and location inside of buildings. These attempts have all met with mediocre results. Harris' wants to conduct experiments using the dual tone approach to see if we can improve performance. Any performance improvement will result in better search and rescue capabilities for the public safety and homeland security markets.