Fermi National Accelerator Laboratory

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Use of Passive Repeaters for Tunnel Surface Communications

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Introduction

Many times there is a need to establish radio communication between the surface and a beam enclosure. When one solicits communication companies for solutions, the answer is often to purchase expensive communication equipment such as repeaters or radiax type cable which can cost in the tens of thousands of dollars. This TM will describe an inexpensive solution to this problem and the results that can be expected. The cost of a passive repeater is $100 - $200 depending on how elaborate one wants to be.

Passive Repeater System

A passive repeater system consists of two antennas connected together with a transmission line. When using VHF or UHF transceivers, one can use 5/8 wave mobile antennas, such as the Larson NMO406-CK for the 400-420 MHz range, with the antenna connected to a 19 inch square piece of aluminum to act as a ground plane. This type of antenna has reasonably good gain, seems to be adequate, and is inexpensive. Another antenna choice is to cut a dipole out of bus wire and solder this wire to a female N connector. Using a dipole seems to work OK in the tunnel and avoids the problem of having a wire sticking down for people to poke their eye with. The cable connecting the antennas should be of good quality so that the signal lost in the cable is minimal. We chose Belden 9913 coax. This cable has a characteristic impedance of 50 ohms and has 2.7 dB/100 ft. of attenuation at 400 MHz.

Design considerations

When we first attempted to use a passive repeater system in the Main Injector tunnel, we found that we were only able to obtain about 100 feet of coverage on either side of the antenna. Obviously this result was disappointing. Upon further investigation we found that we were only able to propagate about 270 feet in the tunnel with two handheld transceivers, HTs, operating at 160MHz and 4 watts output. This was confusing since when we made this test we could see each other and could almost shout for communication. We believe the problem with this attenuation of signal is due to the low frequency cutoff produced by the tunnel acting as a wave guide. From wave guide theory we can find that the equation for this effect in a rectangular tunnel is given by:

$$fc = \frac{c}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$$

where:

fc = low frequency cutoff
c = speed of light
a= tunnel width
b = tunnel height
m and n = mode numbers (integers)

For the Main Injector tunnel, a=3.048 meters, b=2.438 meters. This will give a low frequency cutoff of 49.2 MHz for the lowest order mode of m=l, n=0. Below this frequency theoretically one can not propagate RF. There will also be cutoffs of a higher frequency for other integer values of m and n (i.e. higher order modes). Notice that when m=3 and n=0, fc = 146.6 MHz. It is recommended that the desired frequency of propagation for a given mode be greater than 1.2fc, in this case greater than 177 Mhz. We believe that this effect caused the poor propagation we observed when using 160 MHz in the Main Injector tunnel.

After the 160 MHz test we tried 410 MHz and found that at this higher frequency we were able to communicate 900 feet in the tunnel between two HTs operating at 4 watts. When designing a tunnel communication system one must be careful to avoid this effect. Probably the best advice is to make sure the chosen frequency will propagate down the tunnel by testing it.

Another design consideration is antenna location. Antennas should be located such that they are in line of sight as much as possible. The outside antenna can be located on top of a service building far example. The tunnel antenna is a bit more difficult but should at least be located in a place such that is not shielded by tunnel components.

The antennas used will probably need to be cut to resonance for the desired frequency of operation and should be checked if possible. This step is important to preserve the efficiency of the system.

Test Results

We made several measurements in the Main Injector and Main Ring tunnels using a passive repeater system to communicate with the surface. We also made measurements of point to point communication within the tunnels. In both cases we were dealing with a circular enclosure. Since the Main Injector tunnel is an oval shape, we picked the MI-10 area since this has the largest curvature. For the tunnel to surface tests the person on the surface was located about 50 yards from the antenna of the passive repeater system. The distance from the surface transceiver to the antenna of the passive repeater will affect the results but not to the degree of the tunnel distance to the repeater antenna. Listed below are some of the test results. In all cases we were using two HTs having quarter wave antennas, 4 watts output, and operating FM at 410 MHz. The passive repeater in these tests consisted of two Larson NMO 406-CK antennas mounted on a 19 inch square piece of aluminum and connected together by 125 feet of Belden 9913 coaxial cable. We also tested this system using one Larson antenna topside and a dipole antenna in the tunnel. The results were very similar.

Enclosure/Radius	**Type of communication**	**Approximate distance (Ft)**
Main Injector / 1400 Ft.	Point to point in tunnel	800
Main Injector / 1400 Ft.	Tunnel to surface	500
Main Ring /3283 Ft.	Point to point in tunnel	950
Main Ring /3283 Ft.	Tunnel to surface	510