TELEMETERING VIA LEAKY WAVEGUIDES

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Summary Telemetering through leaky waveguides is a combination of cable transmission and atmospheric transmission. This system carries radio signals in a confined space tube thus making signal transmission through tunnels, mines, and buildings possible. This paper discusses the history of development, the types of leaky waveguide, the transmission characteristics, and the performance evaluation methods.

Introduction Ground telemetry in enclosed or obstructed areas, such as tunnels, mines, and buildings, may be accomplished by using leaky waveguides. They are used as a combination of cable transmission and atmospheric transmission. Because of its confined effective space volume, it is sometimes called "wayside link."

Telemetering, as defined by the name itself means measuring at a distance. In the development of the technology and skills to accomplish such measurements, telemetry engineers have become conversant with many disciplines [1]. This paper, therefore, discusses the transmission link in a general sense of leaky waveguide "communication link" rather than in a restrictive sense of "telemetering link."

History The wayside link is not new. A study by the Bell Laboratories of radio transmission in a Pennsylvania Railroad tunnel under the Hudson River in 1956 has resulted in the concept of radiation from a continuous transmission line along the tunnel instead of from separate antennas [2]. Successful voice communication was accomplished by using twin-lead and solid dielectric coaxial cables up to one mile distance at 159-162 MHz [3].

Small-sized coaxial cables (outer diameter much smaller than the wavelength) having new types of slot as radiating elements were studied by Japanese groups [4]-[6]. The desired radiation power or coupling loss can be designed by varying the dimensions of the slots and by selecting an appropriate pitch length. The leaky coaxial cable of 1 Km in length was experimented in a tunnel on the New Tokaido Line of Japanese National Railroads for telephone communication and vehicular control systems data transmission services at 400 MHz band.

Development in Europe was also underway during this period at a much smaller scale.

The U.S. Department of Transportation funded four signal guide studies [7] started 1968 for possible use on the future High Speed Ground Transportation Vehicles. They range from 30 MHz to 65 GHz. They include leaky coaxial [8], surface waveline [9], dielectric waveguide (10), and leaky circular wavefuide [11]. A different kind of dielectric line referred to as the trench line [12] was also studied. Other software development see for example [19].

The U.S. Air Force also funded a feasibility study [20] of using a leaky waveguide technique for use on its high-speed sleds to carry both telemetry and space-time reference signals. The purpose of using this wayside telemetry system was to avoid the signal attenuation caused by rocket engine plumes and plasma sheath.

Simple slotted coaxial cables are now commercially available [21]. They are highly radiating cables.

System Concept A signal guide has two applications [7], [22]. The first is the traveling wave antenna, where the leaky waveguide works as a radiator for an antenna system and the far field of the radiation is important. A signal is radiated away from the waveguide at all times and energy is lost with or without couplers near by. This is called the fast wave technique. The second is the slow wave technique, where the field is bound to the guide. Coupling is performed by interaction with the fringing field. There is no radiation loss unless it is excited by guide apertures, bends, or imperfections.

The leaky waveguide is extended along the route and couplers or antennas are placed near or connected to the guide. The guide serves as a wave carrying and distributing medium. The type of guide depends on the specific application.

In general, a leaky waveguide telemetering channel should be able to couple signal into and out of the guide at any point near the guide, to transmit signal for the full length of the guide with little distortion, to provide sufficient bandwidth, and to carry the signal with little attenuation.

Transmission Properties There are several sources of echoes in the long guide [14]. Foremost among these are the systematic, multiple, regular structural features such as the guide joints. Even though the individual reflections may be small, in a long guide the reflections tend to be coherent at some frequencies and accumulate to produce major effect. This is called the comb-filter effect [14], [15], [17], [18], [23].

A useful band of frequencies is the maximum band width over which the transmission characteristics satisfy an acceptable criterion for all points within that band. The optimal utilization of the sub-bands depends on the method of modulation. In practice, the absorption spikes of the comb-filter are dispersed over the entire frequency band with smaller magnitudes. This is because the exact spacing of guide sections are not identical. The fluctuation of the lengths disperse the absorption spikes. The spacing between joints can also be varied intentionally to optimize the comb-filter effect [24].

Signal dispersion is also a major transmission problem. A signal which is transmitted through a lossy line may be distorted as a result of the phenomenon known as dispersion. For the case of a lossy line, the phase velocity is a function of frequency. The frequency dependence, in turn, is a function of the geometry, conductivity, permeability, and permitivity of the guide. The individual frequency components or waves which make up the complex input signal are shifted in phase as they are propagated along the guide, the fast waves moving ahead and the slower waves falling behind. Thus, the different frequency components will be delayed differently, or dispersed, resulting in distortion of the original input signal.

The amount of distortion will depend on the degree of departure of the amplitude response from a constant and the phase response from a linear function (18]. The information error rate depends on the type of modulation.

Radiation loss from curved open guides [12] can occur by continuous radiation over the length of the curve or by radiation at points where there is a discontinuous change in the radius of curvature of the guide. A discontinuous change in curvature not only leads to loss but also excites a reflected wave on the guide.

When a movable coupler is adjacent to a guide, the guide characteristic is altered by the loading effect of the coupler. This will result in a coupler mismatch condition which disturbs the matched directivity condition of other couplers near the guide.

Special effort should be made to keep the guide joint effects small. This is rather difficult due to the thermal expansion joints.

The signal magnitude is a function of the distance between the coupler and the guide, the lateral and the rotational positions. Should repeaters were used, the coupled signal magnitude also depends on the number of repeaters between two stations.

Performance Evaluation The long leaky waveguide performance evaluation is very complicated. It depends on the electromagnetic, mechanical, and communication properties. System requirements and methodology for the evaluation of the link must be determined [13] before an actual evaluation can be conducted. This section briefly discusses two types of modulation evaluations by using computer simulations.

(1) Frequency-Division-Multiplex, Frequency Modulation (FDM-FM)--This study considers the method of echo theory, relating the ripple of the phase and amplitude response to the noise which may be produced in the channels transmitted over an FDM-FM channel [14]. The approach is based upon the CCIR standards for noise permitted in a telephone channel over a radio relay. This is broken down by successive allocations to that distortion noise that may be permitted in a mile of transmission line. The response ripple in a mile of guide that would produce this amount of noise in a typical FDM-FM system is determined. Thus the computer simulation response ripple may be judged as to whether it exceeds the limit established by this process. The computer simulation programs [16] allow one to judge the suitability of a guide for specific application where such application can be formulated in terms of limits placed on the amplitude and phase characteristics of the guide.

(2) Pulse-Code Modulation (PCM)--Computer programs have been developed for analyzing pulse signals transmitting through a leaky waveguide [19]. The results depend upon the type of modulation and demodulation. The programs compute the received signal distortion upper bound and the distortion ratio. They are useful in judging the degree of distortion. Alternate programs also compute the distorted output signal as a function of time.

Conclusions The leaky waveguide telemetering link is an application of an old concept. It may be very useful in some specific areas. Computer simulation programs have been developed for such systems. For highly radiating guides installed in irregular environment, the computer programs may not be able to predict the performance closely. In this case, the system must be experimentally determined.

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