BIDIRECTIONAL MICROWAVE REPEATER FOR OBSTACLE DETECTION RADAR IN GUIDED GROUND TRANSPORTATION*

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Abstract

A solid-state microwave bidirectional repeater designed for use in a guided radar system is described. The radar is meant for detecting obstacles lying along the tracks in guided ground transportation systems. An echo-cancellation scheme is proposed for reducing the effect of reflections from impedance mismatches at repeater ports.

Introduction

One of the applications of microwave techniques in railway transportation is in a "guided" radar for detection of obstacles along railway tracks. In particular, a surface-wave radar system[1] is being investigated in which the radar signals are transmitted along a surface wave line (e.g., a dielectric image line consisting of a semicylindrical dielectric mounted on a grounded metal sheet) laid out on the ground along railway tracks. The radar signals are generated in a transmitter aboard the train, coupled to and propagated along the surface-wave line, reflected back from an obstacle (or another train on the same track) along the same surface-wave line, and coupled to the receiver, also aboard the train.

In one such scheme[2], a range of 4.9 km was estimated by using very high power pulsed radar signals (50 kW peak value) in order to overcome the attenuation of the signal with distance. An alternative system is considered here in which bidirectional repeaters are installed at appropriate intervals along the surface-wave line for amplifying the incident and reflected signals, thus increasing the achievable range while at the same time reducing the probability of false alarms.[3] Such a system is shown in Fig. 1. A complete repeater will consist of a bidirectional amplifier with signal launchers at input and output ports. This paper is devoted to a discussion of the design of a bidirectional amplifier for this application.

System Requirements and Component Selection

The considerations dictating the choice of the repeater specifications (e.g., the frequency, bandwidth, power gain and output) and the reasons for selecting the components used are briefly summarized in this section.

It has been reported[2] that the attenuation of surface waveguides is a very sensitive function of frequency. The radar frequency was selected to be 1 GHz because surface waveguides having a low-loss around this frequency are available. For a single frequency pulsed radar system, the minimum repeater bandwidth is limited only by the pulse risetime, but in a system involving multiple frequencies (mentioned later), the required bandwidth may be determined by the range of operating frequencies. A minimum power gain of 12 dB per repeater is required, assuming that the waveguide attenuation is 12 dB/mile including the loss due to launcher, and the repeaters are spaced a mile apart. Very much larger separations would necessitate a high repeater gain (imposing more severe echo problems, to be discussed below) and larger changes of signal level along the line (increasing the probability of false alarm). Detailed considerations of receiver sensitivity, coupler loss, and "worst-case" location of obstacle with respect to the train lead to the conclusion[4] that the repeater need not deliver more than a few milliwatts of output power. An unnecessarily high power level is undesirable both from repeater cost and interference viewpoints. There are no stringent requirements of linearity or ultra-low-noise operation upon the repeater but the evnironmental requirements are very severe due to the expected operating conditions. The present design does not satisfy all of the requirements of ruggedness, wide temperature range, etc. which would be necessary in practice.

Microwave transistors were chosen as the active devices in the repeaters because, at the frequency and power levels involved, the microwave transistor amplifiers have higher stability and wider tolerances of operating conditions as compared to other devices such as negative resistance microwave diodes. The microstrip lines were used for circuit design due to compactness, low cost and ease of large-scale production. The complete

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amplifier was enclosed in a shielded box with coaxial connectors for RF ports, and a 15 V DC supply.

Repeater Circuit Design

Since a microwave transistor amplifier is an uni-directional device, two separate amplifiers were connected by means of circulators, one amplifying signal in one direction and the other in the opposite direction, with four-port circulators used for the isolation of the two paths. A schematic diagram of the repeater circuit is shown in Fig. 2, where A_1 and A_2 are two microwave transistor amplifiers, and C_1 and C_2 are two four-port circulators with port 4 terminated by matched loads (50Ω resistors). As shown in Fig. 2, a signal entering port A of the repeater appears at the input port of amplifier A_1 and is amplified by A_1. This amplified signal passes through the circulator C_2 and appears at port B. Conversely, if a signal is entering at port B, the amplified signal will appear at port A via the amplifier A_2 . Thus the circuit can amplify microwave signals in both directions. Bandpass filters were used to prevent oscillation at lower frequencies. The advantage of this circuit (as compared to the hybrid coil repeaters used in base-band two-wire telephony) is that it does not dissipate half of the signal power in the balancing network.

The design of the two individual transistor amplifiers was carried out in the usual manner and the details are therefore omitted here. Scattering parameters were used for the characterization of microwave transistors and the design of matching circuits for the amplifiers. Since the bandwidth requirement of the repeater is small, single stub tuning circuits were used in the amplifier design. One complete amplifier is shown in Fig. 3. A gain of 14.8 dB and a bandwidth of about 100 MHz at 1 GHz was obtained by using HP-35833E microwave transistor.

Effect of Mismatch

The bidirectional amplifier of Fig. 2 suffers from some limitations caused by impedance mismatches at the input and output ports and by direct coupling between the two ports through electromagnetic fields produced. A mismatch at one port results in a reflected signal which follows the dotted path shown in Fig. 4. This can mask the signal reflected from an obstacle or cause a false alarm. Further, a mismatch at both ports or a direct coupling can cause the system to be unstable due to feedback. (These problems are analogous to the "echo" and "singing" effects well known in telephony[5]). The reflected signal is amplified twice in going around the loop, so that the effective reflection coefficient Γ_e appears to be much worse than the actual reflection coefficient Γ_a at the mismatch. This is another reason for keeping the repeater gain small (by reducing their spacing.) there are three possible methods for reducing the effects due to mismatch and coupling. These are discussed below briefly.

1. Frequency Conversion. One method of circumventing the feedback problems due to a coupling of fields at input and output ports is through the use of more than one frequency in the radar system. On any line segment between two consecutive repeaters, both the forward and reverse traveling signals must have the same frequency but this frequency can change on different consecutive line segments with the repeater carrying out the frequency conversion. Multi-frequency operation has also been proposed for estimating obstacle size.[3] Such schemes increase the complexity and cost of the system and necessitates the use of wide band components in the system.

2. Echo Supression. In principle, an echo-suppressor is a signal-operated switching device which reduces echo by introducing a large loss in the return path upon sensing a signal in the forward path, and vice versa, disabeling the forward path when a return signal is present. The transmission is then no longer truly duplex because signals in both directions cannot pass through the repeater simultaneously. This and other limitations of echo suppressors have been discussed in telephony literature.[5]

3. Echo Cancellation. In an echo canceller, the reflection due to a mismatch is cancelled by intentionally diverting a part of the signal in forward (reverse)direction to reverse (forward) direction in proper phase and at proper amplitude in order to cancel the echo signal. Such a scheme is shown in Fig. 5. This circuit was experimentally implemented and tested. It was found that when the phase and amplitude of the diverted signal were well adjusted the reflected signal could be reduced by more than 30 dB, (i.e., more than the loop gain 2G due to the two amplifiers). The effective reflection coefficient Γ_e was therefore reduced to a value less than the actual reflection coefficient Γ_a.

Conclusions

A Bidirectional L-band solid-state microwave amplifier, using a microwave transistor in microstrip circuitery, has been designed for use in an experimental guided surface-wave radar system for obstacle detection in guided ground transportation. Echo cancellation method was judged to be the most appropriate for reducing the effects of reflection caused by impedance mismatches at the ports of the repeater and was experimentally shown to be satisfactory.

References

1. H. H. Ogilvy, "Radar on the Railways," Electronics and Power, vol. 10, pp. 146-150, May 1964.

2. T. Nakagara and N. Kurauchi, "Millimeter Waveguides with Applications to Railroad Communication", in "Advances in Microwaves" (L. Young, ed.), vol. 4, Academic Press, New York, 1969, pp. 191-300.

3. J. C. Beal, et al., "Continuous-Access Guided Communication (CAGC) for Ground Transportation System", Proc. IEEE, vol. 61, pp. 562-568, May 1973.

4. M. S. Gupta and H. H. Tan, "Solid State Bi-Directional Microwave Repeater for Guided Radar Obstacle Detection in Ground Transportation," Technical Report No. 73-6,

Canadian Institute for Guided Transport, Queen's University, Kingston, Ontario, Canada, June 1973.

5. J. W. Emling and D. Mitchell, "The Effects of Time Delay and Echos on Telephone Conversations," Bell System Tech. Journ., vol. 42, pp. 2869-2891, November 1963.

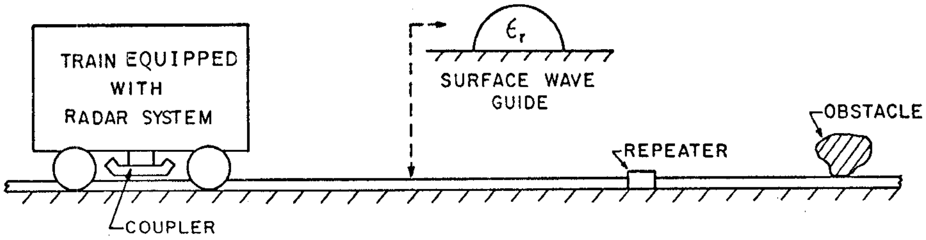

Fig. 1 The Guided Radar Obstacle Detection System.

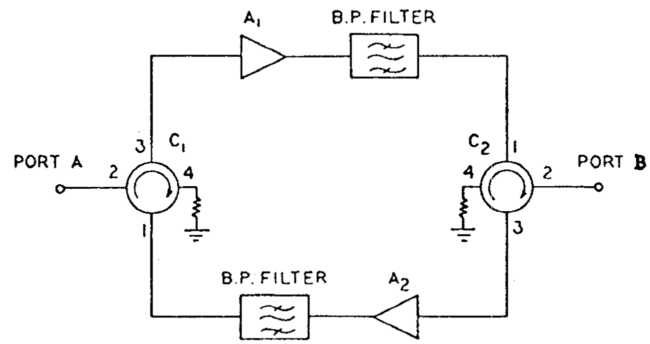

Fig. 2 Bidirectional Repeater Circuit.

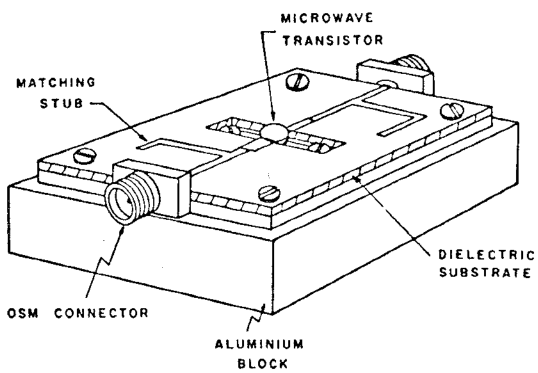

FIG. 3 Single-Stage Microwave Transistor Amplifier in Microstrip Circuit.

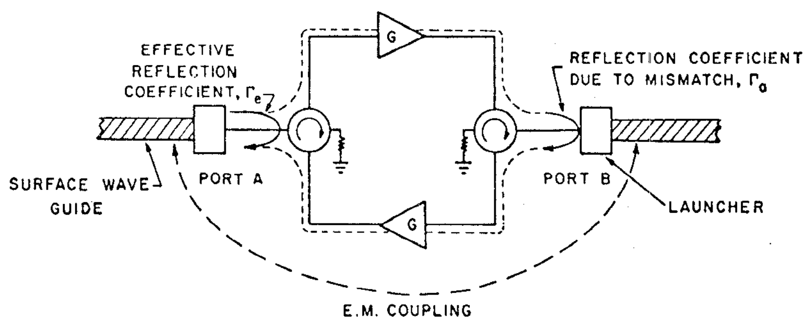

Fig. 4 Reflected Signal Path in Repeater Circuit.

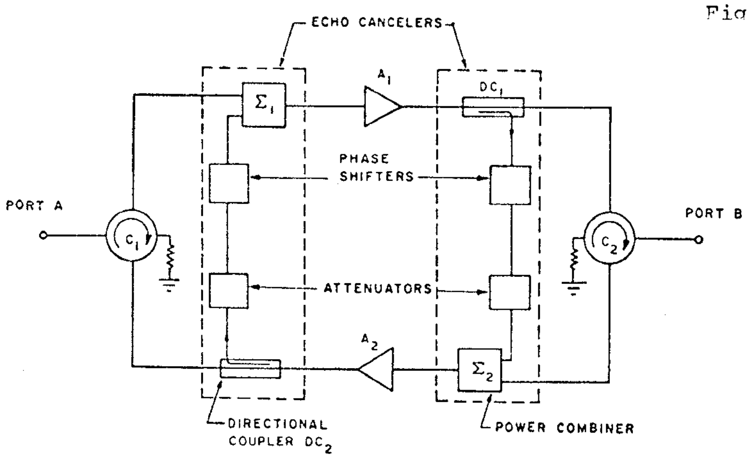

Fig. 5 Schematic Diagram of the Bidirectional Repeater Equipped with Echo Cancellers.

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