6. CONCLUSION
A new type of planar transmission line, modified from the traditional Goubau line, has been proposed. Some different configurations have been demonstrated and the dimensions of this new type of transmission line have been provided. The numerical results, suitable for practical applications, were obtained by using the FEM to obtain the solutions. Comparisons with metallic rectangular waveguide have been given. The analysis shows that this new type of transmission line has advantages such as simplicity, ease of fabrication, and low loss, in comparison with other types of transmission lines at terahertz frequencies.

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effects can make significant changes in antenna patterns. Unfortunately, only experimentally determined electromagnetic-field strengths around the vehicle with the antenna in the appropriate mounting position can reveal the antenna’s true performance; antenna simulation results calculated using an ideal ground plane provide misleading results. Therefore, the experimental results for spatial-field strengths are also included in this paper.

2. ACTIVE ANTENNA SYSTEM DESIGN

The active antenna system includes both passive and active components with an input matching circuit, transistor, and output matching circuit. Figure 1 shows the geometry of the proposed meander-line antenna.

2.1. Passive Antenna Design

The meander-line component of the antenna has compact dimensions of 50 x 50 mm², and is printed on the front of an FR4 substrate (thickness 1.6 mm and relative permittivity 4.4). The antenna ground plane is printed on the bottom side of the substrate as well as partly on the top side. The bottom ground plane is used at the same time as the ground plane of the amplifier connected to the meander line.

It is well known [13, 14] that a folded wire length in a monopole antenna increases the radiation resistance and consequently the input impedance. With this in mind, the meander-line design was optimized using electromagnetic software IE3D [15] to provide 50Ω impedance and omnidirectional directivity. The simulation results reveal the total radiating antenna efficiency $\eta$ is 0.15. Figure 2 reveals the measured input impedance and VSWR of the passive antenna component. To make accurate measurements of the antenna impedance, a $\lambda/4$ metal sleeve (balun) was used to eliminate stray current, along with its undesired radiation, from the coaxial cable.

2.2. Active Antenna Design

The amplifier for the antenna was designed using computer software from Eageware Corporation [16]. Overall amplifier properties were optimized to obtain noise impedance matching between the antenna and transistor stage, and power impedance matching between the amplifier and the 50Ω load. The amplifier consists of a single-stage NE 662 transistor from California Eastern Laboratories coupled to a passive input circuit that provides a low noise figure, and an output matching circuit that provides maximum amplifier gain.

The experimentally measured amplifier gain in the 315-MHz band as a function of frequency is shown in Figure 3. The noise figure of the amplifier is about 2 dB.

3. ANTENNA PATTERN MEASUREMENTS

The measurement site uses an outdoor automobile turntable (Te natronics Ltd.), which can either rotate the antenna under test alone (without a vehicle) or rotate the automobile along with the antenna. The turntable is placed on a hill to block outside reflections from the surrounding environment. The antenna range instrumentation is controlled by a computer that drives the turntable rotation, controls a spectrum analyzer, and transfers measured data to the hard drive and printer. A data point was taken on the 0° elevation amplitude pattern every 2° as the turntable was rotated through a full 360° azimuth. All field-strength measurements are implemented for the designed antenna installed in a 2003 Yukon vehicle (GM).
For a detailed investigation of the design performance, the antenna prototype was fabricated and measured in two different versions: a passive version without the amplifier and an active version with the amplifier. Since the active antenna has a small size of less than 1/10 of the wavelength, it cannot be considered as purely symmetrical or purely antisymmetrical due to the limited-size ground plane. Classical antenna measurement techniques are consequently no longer adequate due to the current flow on the cable connecting the antenna to the receiver. On the other hand, it is difficult to obtain accurate measurement results of the antenna gain and directionality without the cable and mounting structure. Under such conditions, the only way to obtain a valid gain measurement is to test the antenna, connected through the cable to the receiver, while it is mounted in place on the vehicle. Therefore, all antenna-performance measurements were made when the receiving antenna (either the active antenna or its passive subcomponent) was mounted in this fashion. A transmitting Yagi antenna with horizontal polarization was located the far zone of the antenna receiving system in the vehicle in order to provide signal power for the antenna pattern measurement.

4. ANTENNA PATTERN DATA ANALYSIS

The active antenna system is perhaps best understood by first analyzing the performance of the passive meander-line component of the antenna, then comparing the results with the performance of the meander line coupled to the active antenna. Figure 4 shows the radiation pattern for the meander line alone, without the active antenna, when mounted directly under the front dashboard of the vehicle (the front of the vehicle is located at 320°). The gain value $G_a$ averaged over 360° azimuth is $-7.4$ dBi, with a standard deviation $\sigma$ of 4.4 dB. The radiation pattern of a half-wave dipole antenna located at the same place is shown in Figure 5 for comparison. The dipole gain value calculated from the chart data shown in Figure 5 is $-2.8$ dBi, with a $\sigma$ of 5.1 dB. The theoretical gain value of the dipole antenna is 2.15 dBi, and the gain value calculated by our antenna from the radiation-efficiency estimation is $-8.2$ dBi. As can be seen from these results, the vehicle body attenuates the dipole antenna gain, but has minimal effect on the gain value of the meander-line antenna. The difference between the gain values $G_a$ and $G_{dipole}$ measured in the vehicle is 4.6 dBi. Figures 6 and 7 show the radiation-pattern curves for the passive meander-line antenna located on the right-front and rear-roof support pillars of the vehicle. In contrast to the various passive antenna results, Figure 8 reveals the radiation pattern of the active antenna from measurements taken when it was located under the

![Figure 3](image1)

**Figure 3** Amplifier gain

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Gain (dBi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>-16.205</td>
</tr>
<tr>
<td>100.0</td>
<td>-11.277</td>
</tr>
<tr>
<td>150.0</td>
<td>-5.122</td>
</tr>
<tr>
<td>200.0</td>
<td>7.248</td>
</tr>
<tr>
<td>250.0</td>
<td>14.973</td>
</tr>
<tr>
<td>315.0</td>
<td>15.215</td>
</tr>
<tr>
<td>400.0</td>
<td>9.55N</td>
</tr>
<tr>
<td>500.0</td>
<td>-7.455</td>
</tr>
</tbody>
</table>

Table 1: Amplifier gain values

![Figure 4](image2)

**Figure 4** Radiation pattern of the passive meander-line antenna with $G_a = -7.4$ dBi and $\sigma = 4.4$ dB

![Figure 5](image3)

**Figure 5** Radiation pattern of the half-wave dipole with $G_a = -2.8$ dB and $\sigma = 5.1$ dB
front dash of the vehicle. A comparison of the overall active-gain value \( G = G_a G_{\text{amp}} \) and passive antenna gain \( G_a \) shows that the amplifier gain of the active antenna is about 15.4 dB. Neatly affirming these results, this value is approximately the same as the gain of the amplifier alone, as measured in the laboratory.

5. MAXIMUM DETECTION RANGE FOR THE ACTIVE ANTENNA SYSTEM

According to the Friis transmission equation and the pass/loss measurement-based propagation model [17], the signal power at an antenna receiver output is equal to

\[
P_r = \frac{P_t G_t G_{\text{amp}} G_{\text{rec}} \lambda^2}{(4 \pi)^2 D^2},
\]

where \( \lambda \) is the wavelength, \( P_t \) is the transmitting power, \( G_t \) is the transmitter antenna gain, \( G_{\text{rec}} \) is the receiver gain, \( \text{ERP} = P_t \cdot G_t \) is the effective radiated power, \( D \) is the distance between the transmitting and receiving antennas, and \( n \) is a real constant value that is a function of the wireless communication environment [18].

For free-space propagation, \( n = 2 \). Extensive measurements have shown that in flat terrain, \( n \) is between 2.5 and 4 with an accuracy of ±0.6 dB.

Noise power at the receiver output [19] can be estimated as

\[
N = k T_0 B G_{\text{amp}} G_{\text{rec}} \left( \frac{\eta}{T_0} + 1 + \eta - \eta \frac{T_0}{T_0 + F_S} \right),
\]

where \( F_S = F_{\text{amp}} + (F_{\text{rec}} - 1)/G_{\text{amp}} \) is the wireless system noise figure, \( F_{\text{amp}} \) is the amplifier noise figure, \( F_{\text{rec}} \) is the receiver noise figure, \( B \) is the receiver frequency bandwidth, \( T_0 \) is the antenna noise temperature, \( T_0 = 290 \, \text{K} \), and \( k = 1.38 \times 10^{-23} \, \text{J/K} \) is the Boltzman’s constant.

It is known [20] that for the UHF band, \( T_a = T_0 = 290 \, \text{K} \). In this case, Eq. (2) can be simplified to:

\[
N = k T_0 B G_{\text{amp}} G_{\text{rec}} F_S.
\]

Using Eq. (1) and the noise-signal value \( N = k T_0 B G_{\text{amp}} G_{\text{rec}} F_S \), the signal-to-noise ratio at the receiver output can be defined as

\[
\text{SNR} = \frac{\text{ERP} \lambda^2}{(4 \pi)^2 D^2 k T_0 B F_S^2}.
\]

According to Eq. (3), the maximum range of the wireless communication system is given by

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**Figure 6** Radiation pattern of the antenna located on the right-front support pillar with \( G_a = -7.1 \, \text{dBi} \) and \( \sigma = 4.9 \, \text{dB} \)

**Figure 7** Radiation pattern of the antenna located on the rear-roof support pillar with \( G_a = -11.6 \, \text{dBi} \) and \( \sigma = 4.9 \, \text{dB} \)

**Figure 8** Radiation pattern of the active antenna with \( G_a = 9 \, \text{dBi} \) and \( \sigma = 4.1 \, \text{dB} \)
The in-vehicle antenna’s radiation patterns were measured using an automobile turntable. The effects on the radiation pattern of different antenna locations on the vehicle were also investigated. A simple expression was derived that can be used to estimate the improvement in the maximum operating range when using an active-antenna system.

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