Miniaturized Multifunction Shared-Aperture Automobile Antenna for Terrestrial and Satellite Communications

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Abstract

This paper presents a new class of multifunction antenna that can handle terrestrial and satellite communications on automobiles with a single aperture. The antenna is ultrawideband, miniaturized and low-cost, thus attractive for applications on automobiles and other small platforms. The approach is based on new traveling-wave antenna technologies.

Keywords : Antennas Multifunction Ultrawideband Miniaturized Automobile Terrestrial Satellite Communications Traveling-wave Shared-aperture Vehicular

1. Introduction

Research in multifunction antennas for automobile application began two decades ago [e.g., 1], long before the onset of market needs. The research efforts were intensified in the past decade with the phenomenal growth of wireless services, as exemplified by Toyota's plan that "Toyota cars may achieve over the next decade the ultimate goal of just one antenna for a car…. Currently, dozens perform that task" [2]. The difficulties in achieving such a lofty goal were further burdened by most auto manufacturers' mandate that any new automobile antenna must have a thin, conformal, or "hidden" configuration, as well as an aesthetic appeal and low cost, as discussed by this author, among others, in [1], [3] and [4].

However, in recent years several European luxury car makers such as Mercedes Benz and BMW took a different approach by pioneering multifunction antennas that are not conformal, but have a certain eye-catching and aesthetic profile. Surprisingly, their designs have been well embraced in the marketplace. Today, even "dummy" "Shark fin antennas" with a mere shell were installed on some automobiles of lesser prestige as a status symbol.

With this fundamental change in the game, the conformability requirement for vehicular antennas has been greatly relaxed, and this author was inspired to develop a class of miniaturized 3-Dimensional (3-D) Traveling-Wave (TW) antennas with ultra-wide bandwidth [5, 6]. However, the radiation patterns of the antennas are omnidirectional suitable only for terrestrial communications. This paper presents a miniaturized multifunction antenna providing both omnidirectional and unidirectional patterns in a shared aperture so that most satellite and terrestrial communications on an automobile can now be replaced by a single multifunction antenna [7].

2. A Single Multifunction Antenna on a Car

Fig. 1 shows a multifunction TW antenna mounted on the rear edge of the rooftop of a passenger sedan to cover almost all the wireless services available on an automobile as summarized in Table 1. The antenna has two parts: a visible portion as illustrated in Fig. 2, and a hidden part as shown in Fig. 3.

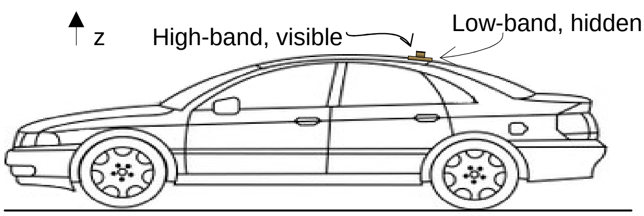

Figure 1: Multifunction TW antenna mounted on rear edge of the rooftop of a passenger sedan.

Table 1: Wireless Services onboard Automobiles

System served	Freq. (MHz)	Pol	Coverage	Sat/Ter	Tx/Rx
AM Radio	0.526-1.607		Omni	Ter	Rx
FM Radio	87-108		Omni	Ter	Rx
Misc. telecom	137-174		Omni	Ter	Tx/Rx
Keyless entry	350		Omni	Ter	Rx
Dig. Video Broad-T	470-862		Omni	Ter	Rx
Misc. Mobile	450-900		Omni	Ter	Tx/Rx
GSM 900/1800	890-960/1710-1880		Omni	Ter	Tx/Rx
PCS (low band)	901-941		Omni	Ter	Tx/Rx
PCS (high band)	1850-1990		Omni	Ter	Tx/Rx
Dig. Aud Broad-T	1452-1492		Omni	Ter	Rx
DECT	1880-1900		Omni	Ter	Tx/Rx
UMTS	1885-2200		Omni	Ter	Tx/Rx
Ultra-wideband	Evolving		Omni	Ter	Tx/Rx
WiMAX	2.4, 2.5, 2.6, 3.5 GHz		Omni	Ter	Tx/Rx
Other Telematics	2.4 to 5.9 GHz, etc.		Omni	Ter	Tx/Rx
GPS L1/L2	1563-1587/1164-1188	RHCP	Uni.hemisp.	Sat	Rx
GLONASS L1/L2	1593-1610/1239-1254	RHCP	Uni.hemisp.	Sat	Rx
Galileo	1164-1591 (6 bands)	RHCP	Uni.hemisp.	Sat	Rx
Compass/Beidou	1164-1591 (5 bands)	RHCP	Uni.hemisp.	Sat	Rx
Iridium	1616-1626.5 MHz	RHCP	Uni.hemisp.	Sat	Tx/Rx
Satellite Radio	2400-2460	RHCP	Uni.hemisp.	Sat	Rx
Geostationary satellite services	1-4 GHz	RHCP	Uni.hemisp.	Sat	Rx

In Fig. 2 the lower part of the antenna covers terrestrial services with an omnidirectional pattern in VP (vertical polarization). At the top is a broadband TW antenna handling satellite services with a unidirectional hemispherical pattern and RHCP (right hand circular polarization). The good performance and low cost were enabled by a new TW antenna technique [8], for which the small 5-cm diameter was achieved by using the slow-wave (SW) technology [9]. The low-band section for frequencies below 600 MHz is hidden in/glass and/or on-glass, thus invisible, as depicted in orange color in Fig. 3, which is a transmission-line antenna with an impedance tuner that can tune frequencies down to the FM band and also pick up AM signals.

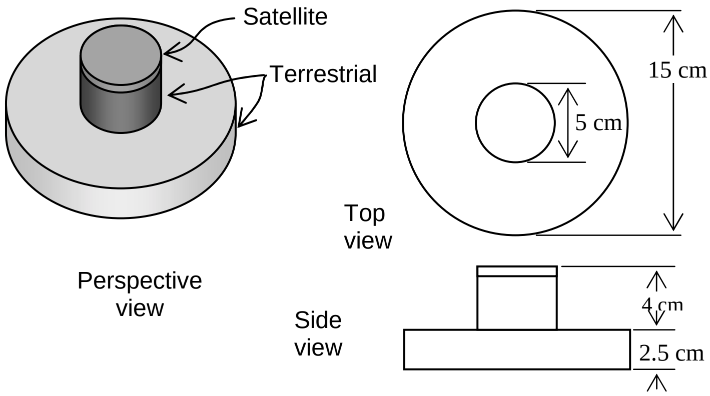

Figure 2: Perspective, top, and side views of the visible part of the antenna in Fig. 1.

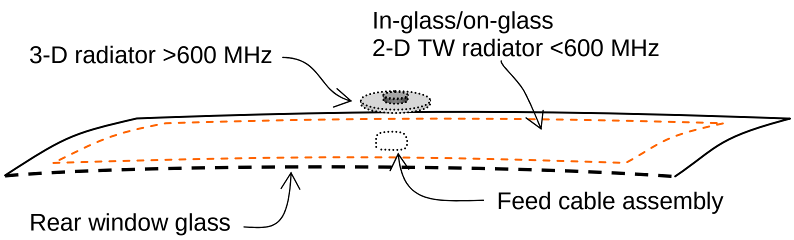

Figure 3: Invisible low-band section (in orange color) of the multifunction antenna in Fig. 1

3. Performance

Several breadboard models, in addition to that of Fig. 2, were designed, fabricated, and tested in WEO's anechoic chamber. Although the efforts had been initially driven by a specific application on an automobile, the project rapidly expanded into technology demonstration on several fundamental issues in a rather free path as the core effort has been an internally funded research. A fundamental interest is how wide a continuous bandwidth can be reached. To this question, measured data for the omnidirectional part of the antenna have shown a bandwidth about

100:1 or more, and a bandwidth of 140:1 was indirectly demonstrated. The full-scale (1:1 scale) model has confirming results, but the test and fabrication difficulties over the corresponding 0.4-46.0 GHz were serious enough at frequencies above 20 GHz that the measured data could not do justice to the merits of the design. Therefore, the use of scale model technique is useful at this stage to circumvent the difficulties in hardware fabrication and test instrumentation.

For example, measured VSWR in Fig. 4 shows a continuous bandwidth of 0.2-23.0 GHz for the omnidirectional section of the multifunction antenna of a 2/1-scale model. Fig. 5 shows the desired omnidirectional pattern at 75º off the z axis (or 15º above the horizon or azimuth plane).

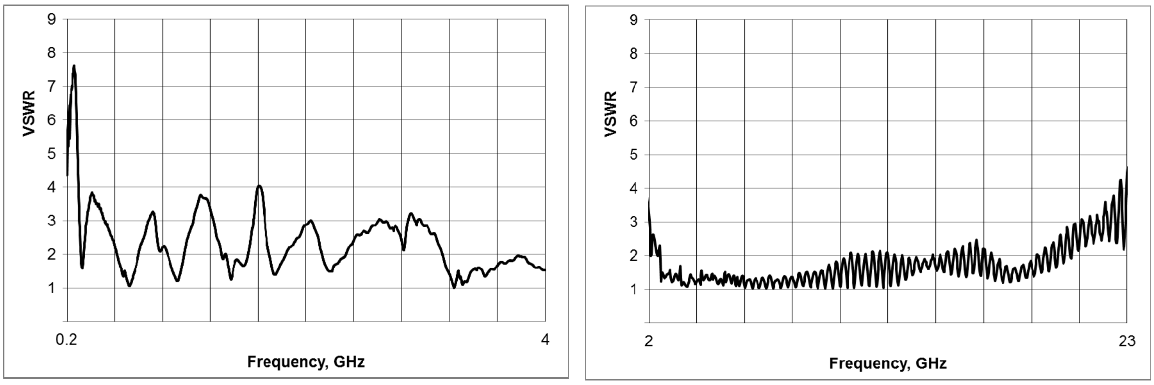

Figure 4: Measured VSWR over 0.2-23 GHz (100:1 bandwidth) of the omnidirectional section.

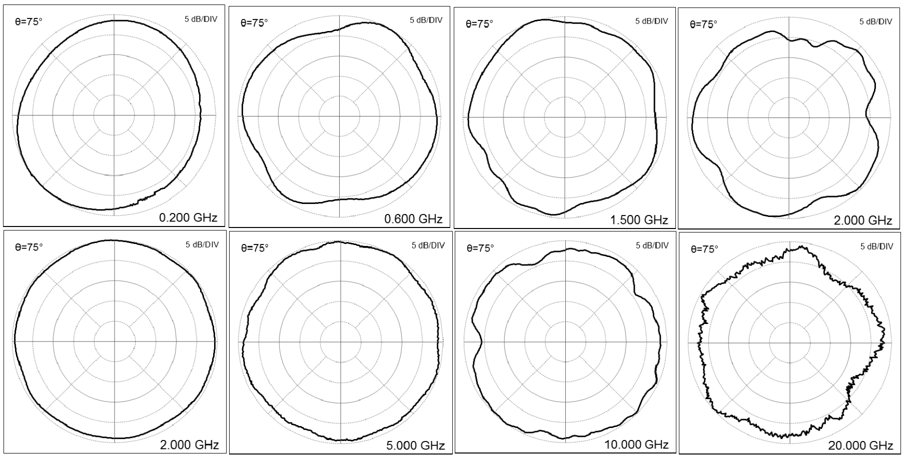

Figure 5: Measured radiation patterns over 0.2-20.0 GHz

Multiband performance far below UHF frequencies using techniques depicted in Fig. 3 was also investigated, and promising data have been observed. Radiation pattern and antenna gain data were also recorded as exemplified by the generally omnidirectional azimuth patterns at an elevation angle of 75º below zenith over 0.2-20.0 GHz, as shown in Fig. 5.

As for the satellite service, the frequencies of interest are generally over 1-4 GHz. Fig. 6 shows measured VSWR of the antenna at satellite service frequencies over 1-8 GHz. As discussed earlier, this part of the antenna employs a new TW antenna technique [8] miniaturized to a small 5-cm diameter by using the slow-wave (SW) technology [9]. The matching structure has not yet been optimized, as can be seen in Fig. 6. However, its radiation patterns are already in a fairly desirable unidirectional hemispherical shape, as shown by the typical measured elevation radiation patterns of RHCP over 1-4 GHz in Fig. 7. Indeed, by using a slow-wave technology [8], size reduction of 40% has been demonstrated in this case, and further size

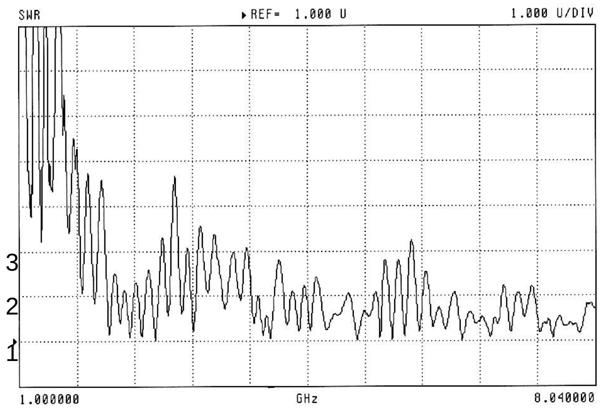

Figure 6: Measured VSWR at satellite service frequencies over 1-8 GHz.

reduction is a distinct possibility.

It is worth mentioning that there are frequency-selective couplers and decouplers between adjacent radiators in the stack of pillbox-shaped TW radiators, depending on whether each is an omnidirectional radiator or a unidirectional radiator. Also, the feed network itself is a complex structure that enables these TW structures to co-exist in an interweaving manner, and simultaneously function with minimal interferences.

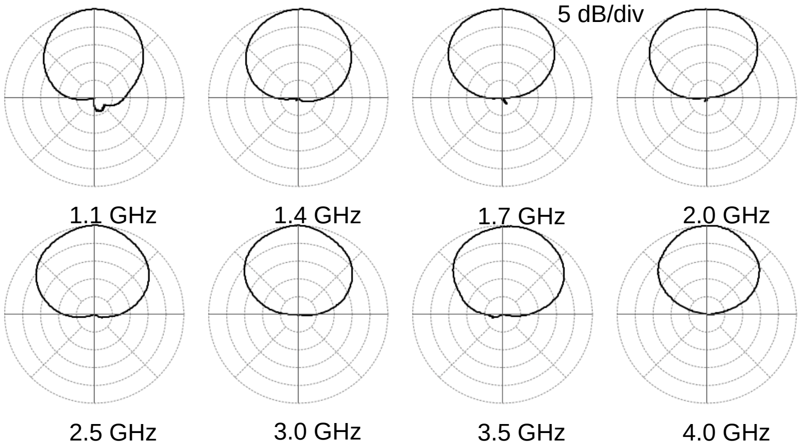

Figure 7: Typical measured elevation radiation patterns of RHCP for satellite services.

4. Conclusions and Future Plan

A new class of integrated multifunction antennas based on new 3-D multi-mode traveling-wave antenna technologies is shown to be capable of handling most terrestrial and satellite communications services available to automobiles by a single radiating aperture. While its size, weight, shape, cost and esthetical appeal are shown to be quite attractive for applications on ground and airborne vehicles, further miniaturization and broadbanding are feasible and are being pursued.

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