Development of Analog Phased Array Antenna for Real-time Location System

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論文内容の要旨

Global Positioning System (GPS) is widely used for locating and tracking objects due to their maturity and large scale implementation. Increase in the number of satellites and number of satellite systems spurs rapid development of detailed digital maps. Many vehicles used in government and commercial sectors, such as taxis, buses, ambulances, and fire trucks are equipped with navigation systems that not only show the current location but constantly trace the movement of vehicle from a monitoring center. Business ventures such as Uber and Grab benefited from the advancement of GPS and invents new service sector to complete the conventional public transport services. Uber and Grab-based applications enable prospective passengers to request door-to-door transport service by merely moving their fingertips at the mobile phone.

From the point of view the security and traceability, demands for real-time location estimation of object or human in indoor environment increases. GPS (Global Positioning System), a satellite-based real-time location tracking system, is widely used in providing critical positioning capabilities to commercial users. Due to inability of transmitted signals to penetrate through the wall of building, GPS is unfitted for indoor environment, such as inside building and factory. Low accuracy in the 1 meter range makes satellite-based location tracking system less suitable for indoor environments. On the other hand, the capability of time difference of arrival (TDOA) based radar, which operates in license-free high band UWB (Ultra Wide Band, 7.25 GHz to 10 GHz), to estimate object location with the accuracy of 10 cm has been reported. TDOA method estimates signal propagation distance by calculating difference between the exact time that signal was sent, and time that signal arrives at receiver. It was reported that transmitted pulse shorter than 1 ns is required for precise indoor object-tracing, so that time difference between incident and arrival signals can be exactly measured.

While UWB systems provide very good accuracy, their maximum operation range is limited by few tens of meters. Realization of a system with high antenna gain for long distance communication systems, such as object tracking in warehouse and factory, becomes main challenge because maximum radiated power spectral density of the existing system is limited by local laws and regulations.

The dissertation presents design methodology to increase antenna gain and maximize scan angle in a wideband phased-array system in GPS-denied environment. Besides, several issues and challenges of existing phased-array system are addressed in this dissertation, as follows:
(1) Intermodulation Distortion Reduction: Designed phase shifter is capable of suppressing high order harmonics on transmitter and receiver paths. Suppression of high order harmonics at the RF front-end reduces intermodulation distortion at low noise amplifier (LNA) in the receiver path.

(2) Beam Squint: Beam squint refers to the changes in scanning angle of phased array antenna when the operating frequency is shifted. Large group delay due to accumulated phase shift in series-fed phased array antenna is the main reason for beam squint to occur.
Corporate-fed phased array antenna has lower beam squint but strict requirement for large phase shift range in individual

phase shifter limits beam scanning angle of the adaptive antenna array.

(3) Scan Angle with Low Bias Voltage: To achieve large scan angle range, large progressive phase shift range is required in phased array antenna. Realization of wide scan angle phased array antenna by using bias voltage within 10v is expected. Parasitic antenna elements are introduced to alter and extend original scan angle, albeit phased array antenna is limited by phase shift range of phase shifters.

The outcome of this dissertation may lead to further development of real time location tracking system. One application area expected to grow rapidly is that of autonomous robots for industrial and shopping system. In the manufacturing factory, wireless controlled autonomous robot offers good alternative to positioning system, such as inductive guide paths and optical guide paths, to transport raw materials. Adoption of phased-array system eases complex infrastructure and installation of existing positioning system. Besides, deployment of beam steering networking in grocery stores may cut down operation cost and number of staff to keep the store, e.g. convenience store, opens 24-hour, and 365 days per year. Similar to the contribution of GPS to Uber application, real time location system introduced in this dissertation for indoor environment may benefit object-monitoring and management systems.

Chapter 1 introduces background and motivations of this dissertation, research objectives, and thesis outline. Chapter 2 explains concept and principle of adaptive phased array antenna and beam steering techniques. Other characteristics of phased array antenna, such as antenna factor, scan angle, power distribution and radiation efficiency are also discussed. In addition, grating lobes in the radiation pattern of antenna array due to separation distance between adjacent antenna elements is elaborated. Also, type of available power distribution network for phased array system is explored to meet requirements for wide scanning angle and uniform power distribution.

Chapter 3 presents the design and implementation 1x4 printed array antenna for multiple layers PCB. Typically, degradation in realized gain and mismatch in input impedance of antenna occur when substrate thickness is reduced. Antenna elements , that is excited by upper two copper layers of four copper layers PCB through proximity coupling, is proposed to alleviate gain degradation caused by thin substrate. In addition, new technique is proposed to suppress electromagnetic leakage in the transmission line. Fabricated 1x4 antenna array demonstrates good far-field radiation patterns and flat gain response across frequencies of interest.

Chapter 4 presents the analysis and design of a full 360 degrees, harmonic-suppressed hybrid coupler phase shifter. Numerical and parametric analyses are introduced as tools of analysis. Simulation and measurement results shows fabricated phase shifter suppresses higher harmonics and achieves relative phase shift range of 360 degrees. Next, harmonic-suppressed phase shifter with discrete varactors and inductors as reflection load is proposed. Continuous relative phase shift of 250 degrees and insertion loss variation less than 1 dB are achieved with 0-to-10V reverse bias voltages. The insertion loss variation is smaller than commercial phase shifters and phase shifters found in the literature.

Chapter 5 presents the integration of antenna array, power divider, phase shifter and parasitic antenna elements on multiple layers PCB to realize phased array antenna. By placing parasitic antennas in between active antenna arrays, it is found that mutual coupling effect increases scan angle range of phased array antenna. The measured far-field radiation patterns of fabricated phased array antenna are matched to simulation results. Proposed work extends maximum scan range from 50 degrees to 60 degrees. It achieves wider scan angle by using lower progressive phase shift compared to other commercially available phased-array system and phased array antennas found in the literature.

Finally, Chapter 6 describes conclusions and future works.