Design and Implementation of Wideband Microstrip Antenna with Resistive and Inductive Loading

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1. Introduction

The standing wave by multiple reflections between the feed and the open ends of an antenna makes distortions of input pulse called “late-time ringing”. One of the widely used techniques for enlarging antenna bandwidth is the application of resistive loading, such as the well-known Wu-King profile [1]. These designs have been concerned with improving the impedance match of antennas over a wide range of frequencies. For these purposes, many kinds of broadband antennas have been reported [2-4]. However the disadvantage of resistive loading is that it reduces the radiation efficiency.

In this paper we propose a resistive and inductive loading technique on the slotted arms of the antenna. The slotted arms have an inductance loading effect for high radiation efficiency of a double-sided feed line antenna. The proposed antenna is implemented and shows good performance to reduce the late-time ringing and more efficient radiation.

2. Characteristic impedance and antenna design

The geometry of the considered antenna is depicted in Fig. 1. The width is 3.99 mm and the length is 102.43 mm of the feed line, respectively. At the end of the feed line the exponentially-tapered antennas begins to achieve a broad frequency bandwidth. A parallel line is employed as a feed line, hence the characteristic impedance will be changed along the line according to the distance of two strips separation. The separated parallel-plate line approximates three types of transmission line models according to the distance of the separation. The microstrip line model can be used to approximate the separated parallel-plate line when the distance of two strips is between 3.99 mm and 1 mm, and the slot-line can be used as a model when the value of the distance is not too large. When two strips are separated too far, a slot-line model is no longer valid. Two-wire line model is preferred for that.

Fig. 1 The geometry of double-sided microstrip antenna
As sown in Fig. 1 solid (metal strip on the top side) and dotted (metal strip on the bottom side) strip lines can be achieved by symmetry. The separation between the strip lines at the end is 42.4 mm, thereby the antenna impedance approximately achieves the intrinsic impedance of free space medium (\( \eta_0 = 377 \Omega \)). The part of the parallel lines of the antenna is copper printed, and the rest part of the lines is graphite printed for resistive loading and slotted for inductive loading on 1.59 mm thick epoxy glass. Compared with a PEC antenna, the resistive loading technique reduces not only the internal multi-reflection but also the radiation efficiency of the antenna. However, the slotted arms have reactance for an efficient radiation. Furthermore we have control of the resistive loading effect by changing the gap of the slots. In other words, the resistive loading increases toward the end of the antenna as the equivalent width of the strip decreases.

To simulate the antenna in a simple way, we consider the antenna to be composed of many pair of dipole array as shown in Fig. 2. The current along the strips can be decomposed into the vertical current and the horizontal current [8].

\[ E_{v\text{total}} = E_{mv} \sin(\phi ((e^{-j\beta_0 \cos \phi} + e^{-j\beta_1 \cos \phi}) \sin \tau_1 + (e^{-j\beta_2 \cos \phi} + e^{-j\beta_3 \cos \phi}) e^{-j\beta d} \sin \tau_2) + \ldots + (e^{-j\beta_0 \cos \phi} + e^{-j\beta_n \cos \phi}) e^{-jn\beta d} \sin \tau_n) \]

\[ E_{h\text{total}} = E_{mh} \cos(\phi ((e^{-j\beta_0 \cos \phi} + e^{-j\beta_1 \cos \phi}) \cos \tau_1 + (e^{-j\beta_2 \cos \phi} + e^{-j\beta_3 \cos \phi}) e^{-j\beta d} \cos \tau_2) + \ldots + (e^{-j\beta_0 \cos \phi} + e^{-j\beta_n \cos \phi}) e^{-jn\beta d} \cos \tau_n) \]

Therefore, the electric field at the target position is the superposition from upper dipole and bottom dipole antennas, expressed as (1) and (2).

Where \( E_{mv} = \frac{j \eta_0 \beta_0 h_0 y e^{-j\beta_0}}{4\pi_0} \) and \( E_{mh} = \frac{j \eta_0 \beta_0 h_0 h_y e^{-j\beta_0}}{4\pi_0} \) are can be taken as constants for fixed frequency. Phase delays between two neighbor pairs of dipoles are implicated in the calculation. Hence the electric fields in far region can be determined from (1) and (2).

3. Numerical simulation and experimental results

For the impedance calculation, we used three types of classic transmission line models (microstrip, slot line, two-wire transmission line) for the proposed antenna. Fig. 3(a) shows that three segments of solid line represent the characteristic impedances each corresponding to microstrip, slot line and two-wire line models versus the distance of upper strip and bottom strip. The dotted one is fitted line through polynomial interpolation. The separated parallel lines are fabricated in 12’s different transmission lines for experimental analysis. The measured results and the curve fitting are shown in Fig. 3(b). It is noted that the measured result matches well with the one by transmission line model.
The antenna having copper printed on feed line and graphite printed on antenna region with slot was implemented as shown in Fig. 4. The radiation patterns at 2.8 GHz and 4.8GHz are shown in Fig. 5. It is compared with the results by the dipole array model and the numerical result (Microwave studio of CST), show good agreements.

To find the current distribution on lines we made simulations using method of moment. In Fig. 6 we present current distributions on the arms for the antennas (PEC antenna: without loading, R antenna: resistive loading only, RL antenna: resistive and inductive loading) at 2GHz, 3.25GHz, and 5GHz. The resistive loading can be useful to substantially suppress currents near the ends. The RL antenna suppresses the current less than the R antenna but the current along the antenna appears smooth distribution which is less frequency – dependent.

To analyze the performance in time domain, we measured reflected signal from a large PEC plane which is placed 10 cm in front of antennas by using a network analyzer (0.5GHz-10.5GHz). The PEC antenna has biggest reflection but it has multiple reflections at 3.5ns in Fig. 7(a). The R antenna has smallest peak reflection, which means bad radiation efficiency. The reflection in the RL antenna is higher than the R antenna maintaining the ripples in similar level with the R antenna.
Fig. 6 Normalized current distribution on antenna (a) PEC antenna (b) R antenna (c) RL antenna

Fig. 7 The reflection signal from target (a) PEC antenna (b) R antenna (resistive loading only) (c) RL antenna (resistive and inductive loading)

4. Conclusions

In this paper, we designed a broadband antenna using a resistive loading technique for short transient pulses to reduce internal reflections within antenna. Also the inductive loading is realized by two arms having slotted line. The internal reflections of the antenna are reduced by adapting the resistive loading, and the radiation efficiency are improved by the inductive loading. Therefore, the proposed antenna can be used to prevent the masking of target signal.

References