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A.Yu. Butrym[1], N.N. Kolchigin[1], S.N. Pivnenko[2]
[1]Radiophysics Dept., Kharkiv National Univ.,
Kharkiv, Ukraine
[2]Oersted-DTU, Electromagentic Systems,
Technical University of Denmark, Kgs. Lyngby, Denmark
e-mail: butrym@univer.kharkov.ua

Resistive Loading that Does not Reduce Performance of a Pulse Antenna

Contents

Abstract

The paper shows several different examples of resistive loading in pulse antennas. It is commonly believed that such a loading reduces efficiency of the antenna. Meanwhile, it is shown that as far as the pulse radiating efficiency is concerned it may be not sacrificed by loading, if the latter is placed properly. The idea is demonstrated on example of resistively loaded Tapered Slot Antenna.

1. Introduction

A great interest in UWB signals and devices has been boosted up by FCC regulations in this field that opened a wide range of opportunities in commercial applications of UWB technology. FCC regulations are formulated in terms of allowed spectrum density and frequency band, while irrelevant to radiating waveform: it may be either short pulse, or quasi-noisy signal, or multiband signal, or wave packet occupying 500 MHz. Any of these signals are considered as UWB. In our further discussion we will focus on short pulses that set some requirements on the radiator: it should have linear phase characteristic, so that it does not disperse the pulse when radiating. Moreover, in many short pulse applications it is also very beneficial to have as low as possible the late-time radiation. For example, in short pulse GPR, if the radiated pulse consists of a main peak and late-time peaks then the main peak reflected from a subsurface object may return back to receiving antenna at the same time with the late-time peaks reflected from the ground surface. This may result in significant S/N reduction after subtraction of the ground reflection. There are other applications, where it is very desirable to have a single pulse, e.g. a monocycle, radiated without late-time ”tail”. For achieving this result, it is common to use resistive loading that suppresses internal reflections from antenna discontinuities, which is the main reason of the late-time radiation.

2. Resistive Loading in Pulse Antennas

One of the first interesting examples of resistive loading is presented in the well-known work by Wu and King [1]. They show that using a gradual resistance along a cylindrical antenna (long dipole) may provide the condition that a decaying traveling wave exists in such antenna. The pulse entering such antenna decays towards its ends without forming any back reflected pulse. As a result the radiation is formed by a single propagating along the antenna current wave and the radiated field, correspondingly, consists of a single peak. This idea was so fruitful that a number of other designs emerged that use gradual resistive loading to provide decaying traveling wave condition with no reflection from the abrupt end of the antenna [2–5]. The price for this good matching is the low efficiency of the obtained antenna. The distributed resistance results in decay of the radiating current wave amplitude and, correspondingly, it radiates less energy. It is known [5] that such a loading reduces the efficiency down to 10-50 %. The main drawback of such loading is that it suppresses the useful currents, which contribute to the main pulse. In further discussion we will compare specifically pulse radiating efficiency of UWB antennas by comparing amplitude and energy of the main radiated peak.

Among other examples of resistive/absorbing elements in antennas to improve pulse radiating efficiency the Large Current Radiator (LCR) by Harmuth should be mentioned [6–8]. In this radiator, it was proposed to shield and suppress with absorber the currents that produce unwanted radiation and thus achieve the short pulse dipole-like radiation. As a result, only small part of the fed energy is radiated. But the essence of the idea is in suppressing unwanted radiation only, while the radiation from the main current sheet is not affected. The main reason for the reduced efficiency of the LCR is that the back sheet cannot be forced to radiate useful signal and the energy going into this part of the antenna cannot be reduced.

Some more good ideas can be found in [9], where a dielectric loaded TEM horn is studied. It is shown that a precursor is radiated due to propagating part of energy on the outer surface of the horn with higher speed than inside the dielectric core. For suppressing the precursor an absorber is then placed on the outer surface. There is surely small energy leakage from the core to the surrounding absorber, but it is negligible. Thus, again, the main effect of using the absorber here is suppressing the currents, which radiate not in time with the main pulse. Another fruitful idea found in [9] is high importance of good matching of all discontinuities of the antenna. Both the end and the feed point of the antenna should produce as low reflection as possible. The standing wave in the antenna is formed mainly due to these two reflecting points. Thus improving matching at the feed point results in that the wave reflected from the end of the antenna goes back to the generator instead of returning to the antenna and radiating late-time pulses.

The idea of good matching at the feed point is implemented in a very interesting way in IRA [10]. Here the feeding arms end with resistive patches that connect them to the reflector. The role of these resistive loading is twofold. First, these usually triangular patches, similarly to the Wu-King profile, result in decaying the current wave, such that when arrived to the reflector its energy is significantly absorbed. Second, there is an abrupt step between the conical arms and the patches and thus a reflected wave is formed there. But, on the other hand, another reflected wave is formed when the reflector converts spherical front into a plane one, and part of this reflected wave is coupled into the feed line and returns to the feed point. Therefore, changing the position and configuration of the patch it is possible to achieve destructive interference of these two waves at the feed point (actually, it cancels only symmetrical TEM part of the wave in the feeding line). In terms of efficiency such a resistive matching seems to be not affecting significantly the overall pulse performance of the antenna, since the patches disturb the fields only in their vicinity that comprises a small part of the overall reflector surface.

Summarizing the examples considered above, it can be said that the resistive loading does not influence pulse efficiency when it absorbs the currents that radiate not in time with the main pulse and thus they do not contribute to the main pulse amplitude.

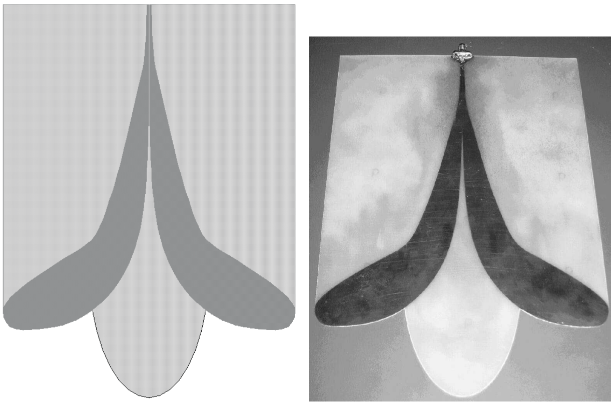
It should also be mentioned that not only resistive, but also capacitive loading can be used to match the ends of the antenna as demonstrated in [12]. Such a matching with several non-equidistantly placed slots distributes the reflection in time without introducing specific resonances.

A good reason to use resistive loading is to prevent wave reflection from abrupt ends of the antenna. However, this problem can be treated differently. For example, it is possible to use interference cancellation due to several scattering centers, when higher modes cannot destroy the radiation because of high directivity, as done in [10]. Another solution is to direct the reflected wave to other path such that it does not reach feed point. An example of this approach is rolled-edge feed horn [11]. Here, the horn arms are smoothly turned back and absorber is placed to suppress the wave directed backwards. In present paper, this approach is adopted for a planar version of such antenna based on Tapered Slot Antenna. Instead of volume absorber, a planar resistive patch is used that provides similar to Wu-King resistance profile to effectively absorb the wave directed backwards. The effectiveness of such design is based on the fact that the wave directed backwards, which is affected by the absorber, does not contribute to the main pulse since its radiation is delayed, and furthermore the longitudinal currents do not radiate in the main axis direction.

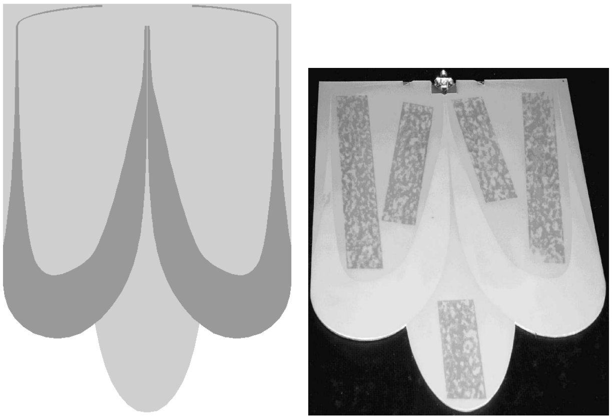
3. Resistively Loaded Tapered Slot Antenna (Trident)

To verify the proposed idea several prototype antennas were fabricated. These are shown in Fig. 1.

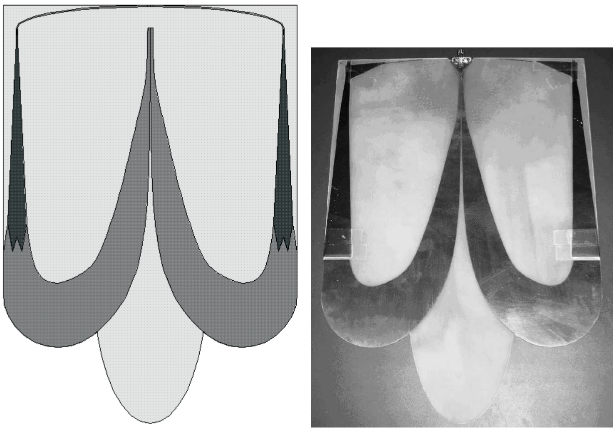
All the antennas were etched on FR4 substrate ($\varepsilon = 4.2$, $h = 0.8$ mm, $\operatorname{tg}\delta = 0.02$). A superstrate of the



(a) Bunny-Ear antenna;



(b) Trident with lumped load;



(c) Trident with distributed load.

Fig. 1. TSA configuration under study.

same material was used to symmetrize fields in the slot and thus reduce cross-polar radiation. In the last antenna conductive graphite paper was used (500 $\Omega/\Box$ in 6 layers) as a resistive loading. The dimensions of the antennas are (210x300 mm).

The proposed antennas originate from the so-called ”Vivaldi” antenna first introduced by Gibson [13]. It is characterized by exponential profile that provides UWB properties of radiation pattern. There exist also a number of modifications known as Tapered Slot Antennas (TSA). These were intensively studied in literature for UWB, but not impulse, applications (see, for example, a number of papers by Schaubert D. H.). It is commonly believed that TSA are dispersive antennas that cannot be used for pulse radiation. However, the dispersive properties actually originate from dispersive feeding used to excite the TSA. When nondispersive balun is used TSA demonstrates very good pulse radiating characteristics. An example of good feeding is the so-called ”Antipodal Vivaldi”, where feeder consists of a gradual transition from microstrip to antipodal slot line [14–16]. This feeding has some drawbacks, such as pattern asymmetry and high cross-polarization level. A new nondispersive transition was reported in [17] that can be used as a balun for TSA. We scaled this design to microwaves and improved it, the details may be found in [18,19]. The balun is very compact (12x12 mm), reflection loss are better then -20 dB in the band from 0–6 GHz, while insertion losses are at the level of -0.45 dB at 6 GHz and smaller at lower frequencies. The balun is used with an SMA connector as can be seen in the photos in Fig. 1.

In order to characterize the pulse radiating performance of the antennas the Normalized Impulse Response as introduced in [9,20] is used. This approach is based on the following convolution relations between signals in feeding lines and radiating/incident fields:

$$\frac{1}{\sqrt{Z_c}} V_{rec}(t) = \vec{h}_n(t,\vec{n}) * \frac{1}{\sqrt{Z_0}} \vec{E}_{inc}(t), \qquad (1)$$

$$\begin{aligned} \frac{1}{\sqrt{Z_0}} \vec{E}_{rad}(t,R,\vec{n}) &= \frac{1}{2\pi Rc} \vec{h}_n(t,\vec{n}) \\ &\quad * \frac{1}{\sqrt{Z_c}} \frac{dV_{exc}(t)}{dt} * \delta(t-R/c) \\ &= \frac{1}{2\pi Rc} \frac{d\vec{h}_n(t,\vec{n})}{dt} * \frac{1}{\sqrt{Z_c}} V_{exc}(t) * \delta(t-R/c). \qquad (2) \end{aligned}$$

The function $\vec{h}_n(t,\vec{n})$ in these relations is known as the Normalized Impulse Response (NIR), it characterizes the antennas in both receiving and transmitting mode. The NIRs of all the antennas were measured in the Frequency Domain with VNA in an anechoic chamber. The details of the experiment, processing, and detailed description of the antennas can be found in [21,22]. The NIRs calculated from the measurements are shown in Fig. 2.

As one can see, all three NIR are almost identical in the first pulse time interval. This is because the tapering that forms this pulse has the same shape for all the antennas. Deviation of the first antenna NIR from the others becomes visible after $\sim$ 150 ps after the main peak: this part of the signal corresponds to radiation from the tips of the antenna arms. The second and third curves separate from each other after $\sim$ 300 ps, when instead of metal strip in the

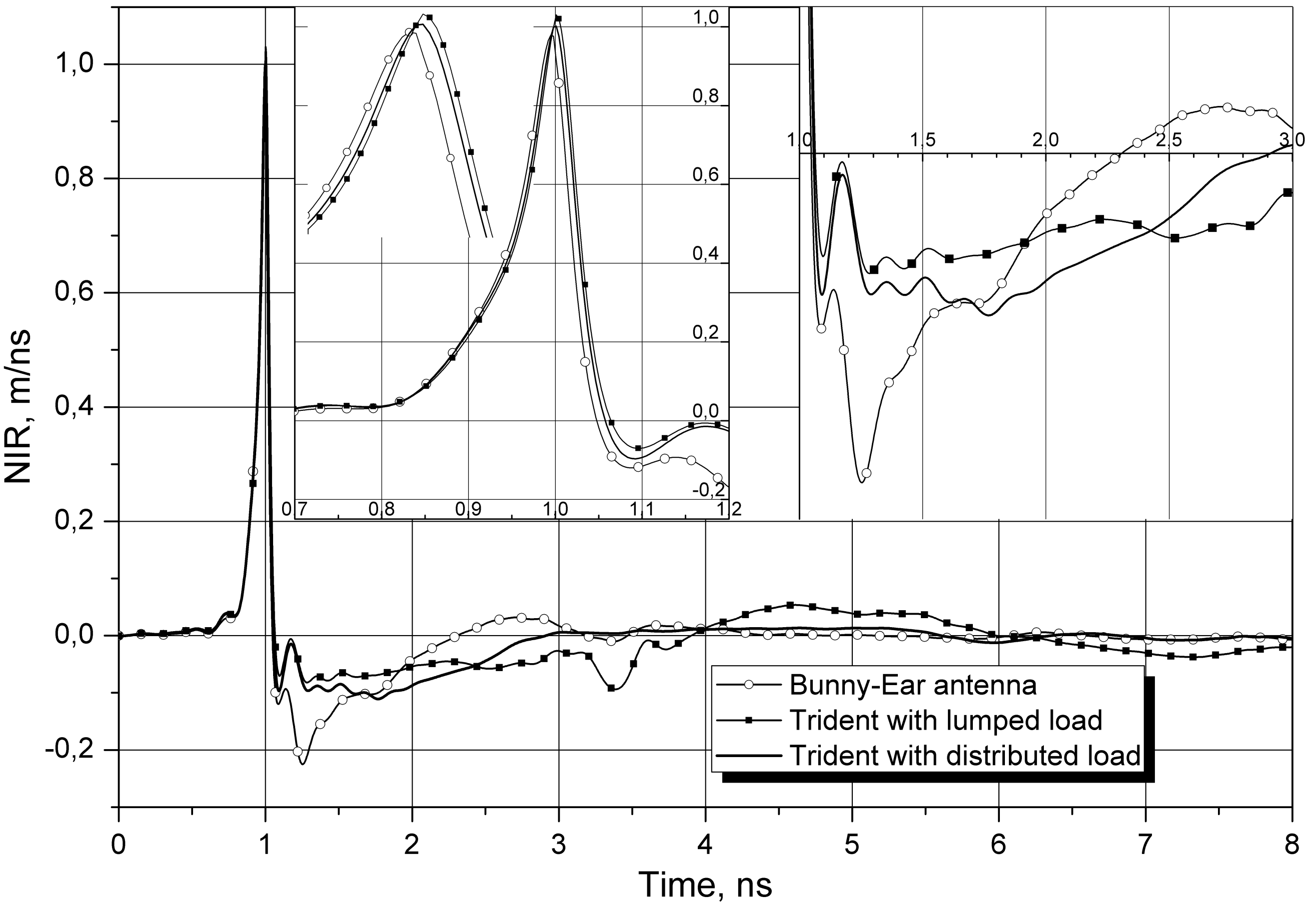


Fig. 2. Measured NIR of the antennas under study.

second antenna the currents meet resistive loading in the third antenna. It should be noted that the resistive loading is made in the form of a triangular patch that provides inverse with distance change in conductivity similar to the Wu-King profile. Such a profile should ideally cause no reflected wave, but in reality such wave is gradually formed. When this wave passes the tip rounding the radiation in the main beam occurs. Thus, the introduced resistive loading does not influence the main radiated peak, which is formed by tapering. On the other hand, it absorbs the reflected wave as can be seen from comparison of the second and third curves. The main pulse duration at the level of half amplitude for all the antennas is ~ 65 ps, peak amplitude is ~ 1.0 m/ns, and the area under the main peak is almost the same (~ 8.8 cm). Late time response for the resistively loaded antenna is very smooth and contains no sharp peaks in contrast to antennas without loading. Transients in the first antenna continue up to 3 ns after the main pulse, but there are no further transients, since the reflected signal passes through a well matched feeder to the feeding line. Long transients in the second curve are attributed to some asymmetry in feeding that cause energy swap between left and right arms.

In the Frequency Domain, the loaded antenna has the return loss $-10 \div -15$ dB in the band $0.3 \div 2$ GHz, $-15 \div -20$ dB in the band $2 \div 5$ GHz, and < 20 dB in the band $5 \div 10$ GHz. For comparison, a traditional Vivaldi of the same size fed by the same balun has shown the return loss < -10 dB starting from 0.9 GHz. Thus the resistive loading not only reduces the late time transients in radiated signal, but also reduces low frequency cut-off by a factor of 3.

4. Conclusions

It has been shown that a resistive loading can be used in such a manner that pulse radiating efficiency is not reduced. It may be the case when the loading absorbs the currents that would radiate earlier or later compared to the main peak. In the proposed design it is implemented by placing the loading in the patches directed backwards that drain the current wave after it reaches the antenna ends.

Similar approach can be used in other pulse antennas. For example, the rolled-edge horn may be improved by using additional surface resistive loading with triangular profile on the back flare. Bow-tie antenna ends can be connected by a shielded resistive sheet, similar to LCR antenna.

The proposed construction has very good characteristics, in terms of efficiency and dispersion, for short pulse application. It is very cheap and simple to fabricate, its planar structure allows easy integration and mounting. All these benefits make the proposed design very attractive for commercial aplications in UWB communication and probing.

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References

[1] Wu T., King R. The cylindrical antenna with nonreflecting resistive loading // IEEE Transactions on Antennas and Propagation. – May 1965. – V. 13, №3. – P. 369–373.

[2] Maloney J.G., Smith G.S. A study of transient radiation from the Wu-King resistive monopole-FDTD analysis and experimental measurements // IEEE Transactions on Antennas and Propagation. – 1993. – V. 41, №5. – P. 668–676.

[3] Montoya T.P., Smith G.S. Resistively-loaded Vee antennas for short-pulse ground penetrating radar // Digest of IEEE Antennas and Propagation Society International Symposium. – 1996. – V. 3. – P. 2068–2071.

[4] Garcia I.S., Bretones A.R., Martin R.G. Pulse-receiving characteristics of V-dipole antennas with resistive loading // IEEE Transactions on Electromagnetic Compatibility. – 1998. – V. 40, № 2. – P. 174–176.

[5] Debalina Chosh, Arijit De, Mary C. Taylor et al. Transmission and Reception by Ultra-Wideband (UWB) Antennas // IEEE Antennas and Propagation Magazine – October 2006. – V. 48, №. 5. – P. 67–99.

[6] Harmuth, Henning F., Nonsinusoidal Waves for Radar and Radio Communication – New York: Academic Press. – 1981. – P. 108–110.

[7] Harmuth, Henning F. and S. Ding-Rong Large-current, short-length radiator for nonsinusoidal waves // IEEE international Symposium on Electromagnetic Compatibility. – 1983. – P. 453–456.

[8] Harmuth, Henning F. Frequency independent shielded loop antenna // U.S. Patent 4.506.267. – March 19, 1985.

[9] Scheers B. Ultra-Wideband Ground Penetrating Radar, with Application to the Detection of Anti Personnel Landmines: // Ph.D. thesis / Université Catholique de Louvain, Laboratoire D'Hyperfr?quences. – Louvain-la-Neuve (Belgium). – March 2001. – 277 p.

[10] C.E. Baum, E.G. Farr and D.V. Giri Review of Impulse-Radiating Antennas in W.R.Stone (ed.), Reviews of Radio Science 1996-1999. – New York,Wiley: IEEE Press. – 1999. – Chapter 12.

[11] Burnside, Walter D. and Chiwei Chuang An aperture matched horn design // IEEE Transactions on Antennas and Propagation – July 1982. – V. 30. – P. 7090–796.

[12] A.A. Lestari, A.G. Yarovoy, and L.P. Ligthart, Analysis of RC loading profiles for antenna bandwidth improvement // IEEE Int. Antennas Propagat. Symp. Dig. – June 2003. – V. 41. – P. 632–635.

[13] Gibson P.J. The Vivaldi aerial // Proc. 9th European Microwave Conf. – Brighton (UK). – 1979. – P. 101–105.

[14] Fourikis N., Lioutas N., Shuley N. V. Parametric study of the co- and crosspolarisation characteristics of tapered planar and antipodal slotline antennas // IEE Proceedings H: Microwaves, Antennas and Propagation. – Feb. 1993. – V. 140, №1. – P. 17–22.

[15] Langley J.D.S., Hall P.S., and Newham P. Balanced antipodal Vivaldi antenna for wide bandwidth phased arrays // IEE Proc.-Microwave. Antennas Propag. – April 1996. – V. 143, №2. – P. 97–102.

[16] Z.N. Chen, M.J. Amman, X. Qing et al. Planar Antennas // IEEE Microwave Magazine – December 2006. – V. 7, №. 6. – P. 63–73.

[17] Kim S. et al. Ultra-wideband (from DC to 110 GHz) CPW to CPS transition // Electronics Letters. – 20 June 2002. – V. 38, №13. – P. 622–623.

[18] Butrym A. and Pivnenko S. CPW to CPS transition for feeding UWB antennas // Proc. 2nd International Workshop on "Ultrawideband and Ultrashort Impulse Signals"(UWBUSIS'04). – Sevastopol (Ukraine). – September 19–22, 2004. – P. 107–108.

[19] Butrym, A., Pivnenko S. CPW to CPS transition for feeding UWB antennas // IEEE Aerospace and Electronic Systems Magazine, – 2006. – V. 21, № 2. – P. 21–23.

[20] Farr E.G. and Baum C.E. Time Domain Characterization of Antennas with TEM Feeds // Sensor and Simulation Notes. – 1998. – Note 426.

[21] A. Butrym and S. Pivnenko A Tapered Coplanar Strip Antenna with Improved Matching, Chapter 38 in Ultra-Wideband Short-Pulse Electromagnetics 7 book ed. by Frank Sabath. – Springer. – 2007. – P. 344–355.

[22] Butrym, A., Pivnenko, S., Kolchigin, N. Processing band-limited antenna measurements to reconstruct antenna impulse responce on example of resistively loaded Vivaldi antenna // Proceedings of the European Conference on Antennas and Propagation, Nice, France. – 2006.