A Novel Printed Full-Wave Yagi-Uda Antenna

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Abstract – **This letter presents a novel printed Yagi-Uda antenna with straight fullwave dipoles. Antenna is single layered and has 11.6Bi gain; it is much simpler and has more than 50% smaller dimensions compared to Landstorfer modification of Yagi-Uda antenna.**

Keywords – **Fullwave loaded dipoles, Landstorfer's arrays, printed arrays, spatial power combining, Yagi-Uda arrays.**

I. INTRODUCTION

Application of dipoles longer than half-wave in antenna design are originally proposed by Landstorfer. As he has shown by utilize such dipoles in antenna design (e.g. in Yagi-Uda array) it can be achieved more gain, for the same antenna length, than with antenna built with halfwave dipoles. This is well explained in [2] and [3]. At the same time, feeding of such antenna is quite simple and required number of power splitters/combiners is less by factor two when such antennas are grouped in an array [1]. Landstorfer suggested a Yagi-Uda antenna with 1.5λ long dipoles (in air) placed at proper distances and shaped in 2D or even 3D space to maximally phase all current elements and achieve best farfield performance, see example in Fig. 1. Directivity of such an antenna is around 11.7dBi, [2] and [3].

Antenna proposed by Landstorfer has some disadvantages, two of them are most important: its large dimensions and complicated dipole shapes. The first disadvantage is emerged when one try to use such an antenna in antenna array – grating lobes will appear.

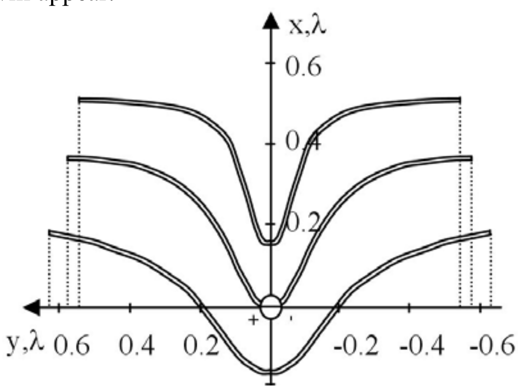

Fig. 1. Landstorfer Yagi-Uda array.

The second is mainly connected to difficulties in design process of such an antenna – optimization of the antenna with Landstorfer's dipoles is complicated and also its realization.

Instead of utilize shaped Landstorfer's dipoles in Yagi design this paper proposes application of straight fullwave lengthy dipoles, tuned by means of inserted lumped reactance.

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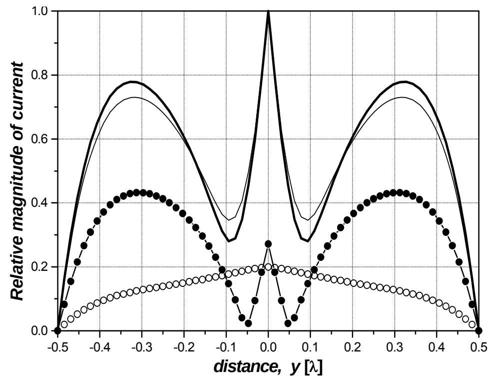
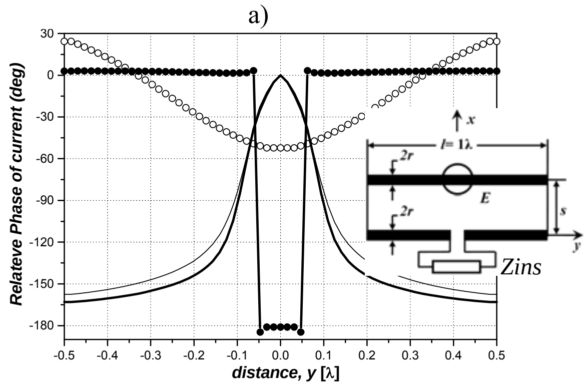


a)



b)

Fig. 2. Current distribution along fed and passive wire dipole in air
a) Relative magnitude, b) Relative phase
l=1λ, r=0.025λ, s=0.25λ
— driver, no *Xins* (*Xins*=0) o-o- passive, no *Xins* (*Xins*=0).
— driver, *Xins*=150 Ω ●■●■ passive, *Xins*=150 Ω

Unlike to halfwave case, by inserting proper reactance in fullwave passive dipole complete shape of current distribution along dipole is changed, i.e. not only relative levels of the magnitude and phase. A novel Yagi-Uda antenna has been designed by utilizing such dipoles and conclusions are verified through its realization and measurements.

II. PHENOMENON DESCRIPTION

Current distribution along driven dipole is generally known. For thin dipoles, this distribution is converged to sinusoidal distribution. A passive dipole (i.e. not directly fed) whose length is near halfwave also has sinusoidal-like distribution.

But, when length of a passive dipole exceeds halfwave, current distribution is changed and may be quite different in comparison to sinusoidal-like distribution of fed dipole of the same length even in thin dipoles. This is well pronounced for fullwave or greater dipoles length. Also, this current distribution is much affected by inserted lumped impedance and driven to passive dipole spacing [1]. Next example, in Fig. 2, well illustrates this phenomenon.

Fig. 2, a) and b), shows relative magnitude and phase of current distribution along driven and passive dipole i.e. both current distributions (I_d (y) and I_p (y)) are normalized with respect to feed current of driven dipole I_{feed} and quantities $I_d(y)/I_{feed}$, $I_p(y)/I_{feed}$ are shown. The figures show two cases for two values of parameter X_{ins}. In the first case passive dipole without lumped reactance (X_{ins}=0) is used and current distribution along driven dipole is quasi-sinusoidal. At the same time, passive dipole current distribution is quite different and it resembles parabolic distribution with maximum of magnitude at the center of dipole instead at center of monopole, as for driven dipole. Maximal current on passive dipole is about 15÷20% of that for driven dipole. So, passive dipole is untuned. By using such dipoles we cannot build a Yagi-Uda antenna.

In the second case, inserted reactance is used to tune passive element. As we can see in Fig. 2, by adding appropriately chosen lumped reactance (Z_{ins}= jX_{ins}= j150 Ω) shape of current distribution is substantially changed from parabolic-like to sinusoidal-like distribution similar to that of driven dipole. Maximal current of passive dipole is enlarged more than 4 times and it reaches level of 55% of maximal current of driven dipole. Phase distribution is changed from one where phase are spread in wide interval of values to almost phase constant distribution, which is more desirable when passive dipole is used in antenna array.

From above discussion it is apparent why in Yagi-Uda design straight dipoles longer than halfwave (e.g. near fullwave dipoles) placed at common distances (around 0.2 λ) were not used. Namely, such dipoles are initially untuned and there is no well-known effect of gain increase when parasitic dipoles are added, as in case when halfwave dipoles are used

III. DESCRIPTION OF REALIZED ANTENNA

To verify results emerging from simulations a 3-element Yagi-Uda antenna has been fabricated with tuned straight passive dipoles and shown in Fig. 3.

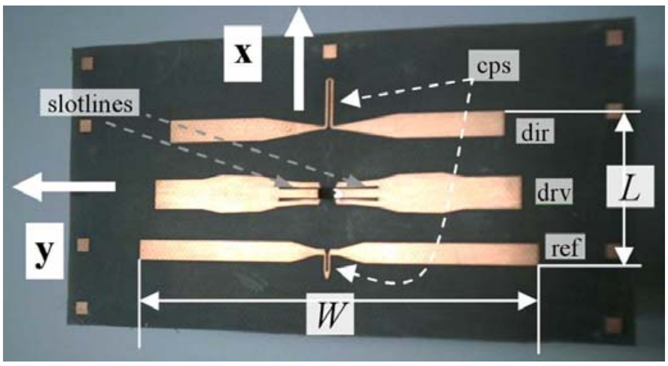


Fig. 3. Realized novel Yagi-Uda antenna with straight tuned dipoles (scalable).

This antenna realization is mainly intended to test achievable gain and efficiency of the antenna.

Because in [1] it has been shown that Yagi antenna with straight dipoles as short as $1\lambda_0$ can be realized, in this antenna realization it is not required that the dipole length have to be maximally $1\lambda_0$ long and it is set as a free parameter for adjusting antenna resistance to 50 Ω just for simpler measurement. There are three reasons for that:

- It facilitates optimization as dipole length strong affects antenna resistance,
- This is single antenna so we are not dealing with grating lobes problem,
- in applications matching impedance is typically input or output impedance of an amplifier which is usually different from 50Ω.

Optimization process gives length of dipoles longer than fullwave. Although overall dimensions of realized antenna are WxL = 1.2 λ_0 x 0.37 λ_0 it still remains smaller than Landstorfer antennas for about 50%.

Of course, when antenna is intended for grouping in E plane, dipoles longer than $1\lambda_0$ can not be used, as grating lobes appear. With proposed novel design it is not difficult to satisfied that, e.g. in [1] is described 3-element wire yagi design with fullwave dipoles in air. Compared to Landstorfer's antenna it has 20% smaller lateral and 110% smaller longitudinal dimensions with practically same directivity (D=11.6dBi). The antenna dimension is only $0.32\lambda_0$ x $1\lambda_0$. So it is clear such antennas can be arrayed in E plane without grating lobes.

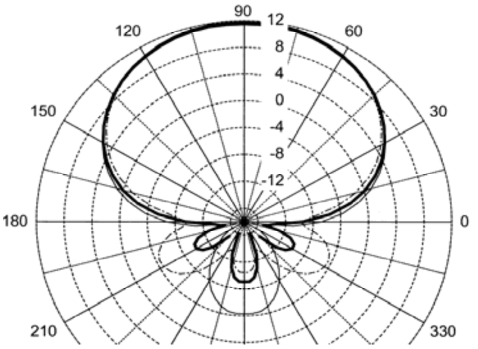
The antenna has been designed on the substrate to work in C band. Full attention has been taken to reduce additional losses so high efficiency and gain of the antenna is obtained and its performance can be consistently compared to those of Landstorfer antenna, although its working frequency is about ten times higher.

The antenna consists of three dipoles: the middle one is fed and the outer two are passive - the reflector being below and the director above. The antenna is realized on dielectric substrate ε_r=2.17, tanδ=0.0009, of thickness h=0.254 mm. Inserted reactance are realized in CPS technique. Dipoles spacing is about 0.2λ. Simple slotline stubs (Fig. 3) are used to compensate antenna reactance as no optimization has been performed for broadening of its frequency bandwidth.

IV. RESULTS

Radiation pattern of the antenna in principal planes (H, E planes) are shown in Fig. 4 a) and b) for three frequencies. As it can be seen from these figures at central frequency side lobe suppression is better than 22 dB in H and 12 dB in E plane. Also from these figures it can be seen that side lobes, especially in E plane, rises with frequency which indicate that lengthening of dipoles to adjust antenna impedance to 50Ω rises side lobes in E plane. So, in an E plane antenna system one have to keep element length close or somewhat less than $1\lambda_0$ in order to eliminate grating lobes and antenna resistance should be adjusted by other parameters, such as dipole width.

Gain of the realized antenna as function of frequency is shown in Fig. 5. Maximal value is 11.6dBi. Antenna gain bandwidth (*Gmax*-3dB) is about 6%. It should be pointed out that from 6 to 10 dipoles are necessary to achieve such gain with classical Yagi-Uda antenna with halfwave dipoles [2]-[5]. This clearly approves advantages of the antenna described in the paper or Landstorfer Yagi antenna.



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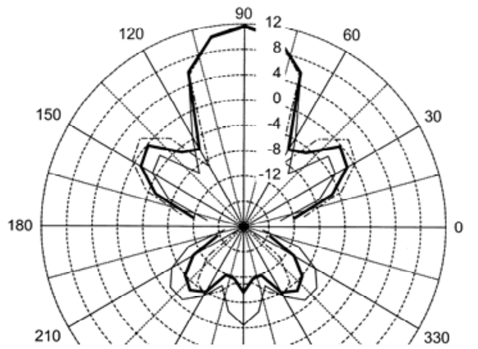

b)

Fig. 4. Radiation pattern [6] of fullwave Yagi antenna with tuned dipoles in:

a) H plane b) E plane

—— f=6.20 GHz; ▬▬ f=6.25 GHz; – · – · f=6.30 GHz

VSWR of realized antenna as function of frequency is also shown in Fig. 5. The best VSWR is at 6.18GHz and its value is 1.2. Bandwidth for VSWR≤ 2.5 is about 5 %.

V. Conclusion

The letter describes a novel printed Yagi-Uda antenna and a method for tuning current distribution along straight fullwave passive dipoles. The method enables realization of simpler antenna with straight dipoles instead with complicated Landstorfer's dipole shapes in 2D/3D space. Based on

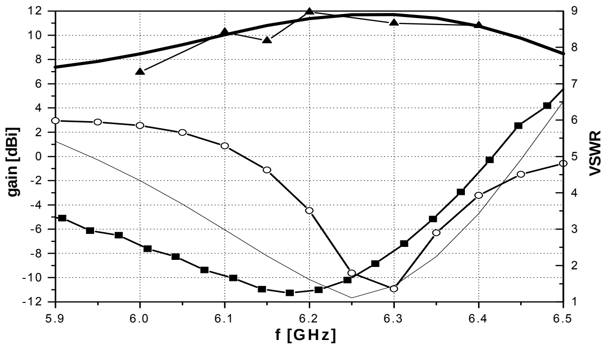

Fig. 5 Gain and SWR of realized Yagi antenna with tuned dipoles

▬▬ G, simulated [6] ➨▲➨ G, measured

—— VSWR, simulated [6] ■–■– VSWR, measured

o-o- Back radiation, simulated [6]

comparison of measured and simulated results it can be concluded that efficiency of antenna is high and losses are less than 0.3dB. Advantages of proposed antenna over Landstorfer one is that lateral dimension of described antenna although in fulwave range can be easy reduced down to $1\lambda_0$ and thus enable antenna arraying in the E plane without grating lobes. Also optimization of the antenna is much easer and it can find applications as an antenna element in antenna systems and in spatial power combiners in tray configuration. Printed antenna can be integrated with other passive and active components.

Acknowledgement

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