An Educational Training Kit for an Efficient GPS Anti-Jamming System

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Abstract—Global positioning system (GPS) is one of the key satellite-based radio technology providing navigational services on earth or near earth. The increasing usage of GPS applications in daily life has proved that students/researchers of many educational departments including information and communication technology (ICT) are particularly interested to learn and visualize the GPS anti-jamming techniques in a simpler way in their major communication courses. It is a fact that GPS radio signal is vulnerable in various ways to jamming signals launched by malicious elements. The traditional available GPS anti-jamming techniques generally involve either added hardware and/or computational complexity which introduce difficulty for students to understand the basic concepts. As an alternative, this paper presents a simpler GPS anti-jamming system kit based on L1-band (1.575 GHz) of GPS for education purpose. More specifically, the proposed antenna array, integrated with two couplers, cancels out the jamming signal in radio frequency (RF) domain using sum and difference patterns generated by the latter. The simulated and measured results, in terms of scattering parameters and power profiles, of the proposed system have shown that the jamming signal can be eliminated with less complexity. Eventually, the proposed GPS anti-jamming system has great potential to be used in ICT related disciplines for learning and training purposes.

Keywords—Global positioning system, Learning, ICT, Antenna arrays

1 Introduction

The scope of emerging technologies in learning is increasing day-by-day where many researchers come under a common goal and start to develop the solutions of the problems specially related to engineering education. This approach of collaboratively learning and development particularly can be helpful in enhancing the engineering labs infrastructure and human skills [1]. Bearing this in mind, this paper is dealing with a global positioning system (GPS) training kit design which can be used as a learning tool for information and communication technology (ICT) students/researchers.

The GPS, initially designed for military purposes, provides geo-location and navigation information from more than 20,000 kilometers above the earth using approximately 24 satellite systems. Nowadays, it provides uninterruptable services to a wide range of application scenarios from military to civilian organizations using frequency bands L1/L2/L5 (1.575/1.227/1.176 GHz) [2]. Currently, GPS is being used in industrial sector wherever information regarding time, location, heading and velocity is desired [3, 4, 5]. The well-known applications of GPS include positioning, navigation, surveying, security, geographic mapping, television signals broadcasting, aviation, and surveillance and so on. Since 2000, GPS has been used actively in several civilian sectors. However, a civilian GPS receiver, as compared to military GPS receiver, is more vulnerable to jamming signals because all the signal characteristics (e.g., code, frequency, and modulation method) are open to public [6]. Thus, in various courses related to ICT discipline, students/researchers are generally interested to learn the basic functionality of GPS operations including jamming and anti-jamming techniques.

A GPS jammer is a self-contained transmitter device used to jam the original GPS signal by sending radio signals of the same frequency i.e., L1-band (1.575 GHz), with high signal power e.g., greater than 56 dB from the original GPS signal (~ -120 dBm). Once this occurs, the GPS receiver becomes unable to perform its normal functionality. Thus, it is necessary to study and to develop anti-jamming techniques to provide continuous GPS signal access to the devices.

This paper presents a simple approach for GPS anti-jamming which could be easily understood and used by fresh ICT students in their major communication courses. The proposed approach consists of patch antenna array and coupler, designed at 1.575 GHz GPS band. The rest of the paper is organized in the following manner. Section 2 and 3 present the literature review and the proposed methodology, respectively. The simulation and measurement results observed and experimental setups (with and without jamming sources) assumed, are provided in section 4. Finally, we conclude the paper in Section 5.

2 Background and Literature Review

To explore the effects of GPS jamming and its mitigation concepts, various studies and educational tools/kits have been proposed in literature which are mainly related to digital signal processing and antenna array processing techniques. For instance, an anti-jamming GPS receiver that removes the jamming effects and preserves the GPS signal phase continuity is proposed in [7]. However, the proposed algorithm is highly complex in terms of computation. Similarly, interference produced by jamming to the GPS signals can be eliminated by using adaptive signal processing [8, 9]. These methods require jammer synthesis based on time-frequency distributions and the performance is compromise between antenna array size and computational complexity. More specifically, the techniques like adaptive array processing allow exploitation of the spatial domain for further improved anti-jamming and signal protection [9-11] with additional burden of high dimensional signal processing matrices. In a slightly different approach, a statistical space-time null widening (SSTNW) method has been proposed in [10] which suppresses interferences effectively in high dynamic conditions and is able to remove disturbance by non-ideal factors. In the antenna-based approaches, pattern and polarization diversity to enable null-steering has been proposed in [11] that suppresses up to two jamming signals incident from the angular region close to horizon. It introduces additional hardware complexity on the front-end. Similarly, [12] presents a high-temperature stable antenna array applied to an adaptive anti-jamming system in satellite navigation. Additionally, in [13], a 5-element antenna array-based GPS anti-jamming technique is proposed which is able to provide nulls in two directions at the cost of increased hardware.

As evident, majority of the reported anti-jamming approaches either require sophisticated signal processing algorithms or complex hardware structures which increase the computational and/or hardware burden in the GPS receivers. Eventually, it becomes somehow difficult for fresh university students from ICT related disciplines to learn the basic concepts related to GPS anti-jamming. As an alternative, this paper presents a simple and easy to understand approach for the GPS anti-jamming which can be implemented in the radio frequency (RF) domain. Utilizing an array of two antennas and associated couplers, the sum and difference patterns of the incoming RF signal are combined in a way to suppress the high-power jamming signal without deteriorating the lower power GPS signal.

3 Proposed Methodology

The proposed approach for GPS anti-jamming in RF domain, as shown in Fig. 1, includes an array of two microstrip patch antennas integrated with two 180^0 hybrid rat race couplers (ring couplers) and a reference GPS signal. The combination, working at L1 frequency band (1.575 GHz), generates the sum and difference pattern of the incoming input signal by introducing 0^0 and 180^0 phase differences, respectively. More specifically, the received jamming plus GPS signal on the antenna array is processed in such a way that one of the antenna elements (i.e., Antenna 1) signal is sent towards first coupler's input port. While, on other input port, we provide a GPS reference signal to obtain the jamming signal only on the difference port (delta port -Δ_1). Furthermore, the second antenna element's signal (jamming plus GPS) and the jamming signal coming from the first coupler's delta port are provided as input to the second coupler. Thus, the original GPS signal is easily extracted at delta port (Δ_2) of coupler 2 utilizing simple arithmetic implemented through couplers. In this way, the high amplitude jamming signal can be removed and the original GPS signal after recovering can be made available for further processing without (saturating) the GPS receiver. The design of antenna array and coupler are described below.

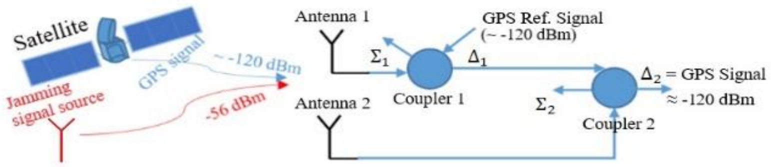
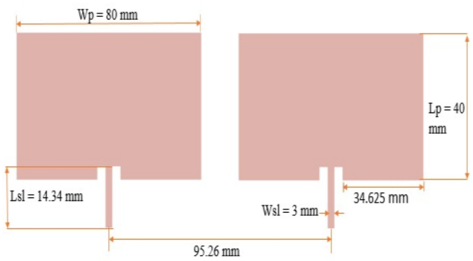


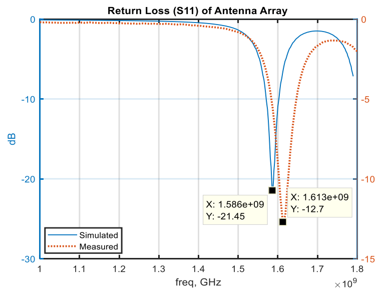
Fig. 1. Block diagram of the proposed GPS anti-jamming technique

a) Antenna array design

The microstrip patch antenna (MPA) is a popular antenna because of the ease of fabrication on the printed circuit board (PCB). Several configurations can be used to feed microstrip patch antennas such as probe feed, microstrip edge feed with inset transmission line (TL), and quarter wave transformer matched TL [14, 15]. In this work, an inset fed MPA array of two elements separated by 0.5λ distance, at L1 band using FR4 substrate (ϵ_r= 4.5, h=1.6mm, and tangent loss= 0.02) has been designed. The simulated antenna array is shown in Fig. 2 (a) with all the design parameters. The obtained simulation results show that the array resonates at 1.575 GHz frequency with return loss (S11) parameter of -21.45 dB, as shown in Fig. 2 (b). Moreover, the directivity obtained is 7.55 dBi. Furthermore, the fabricated MPA was tested using vector network analyzer (VNA). The measured scattering parameter (S11) is illustrated in Fig. 2(b), which shows that the fabricated antenna array resonates at 1.61 GHz with return loss of -12.7 dB.



a) Simulated MPA array

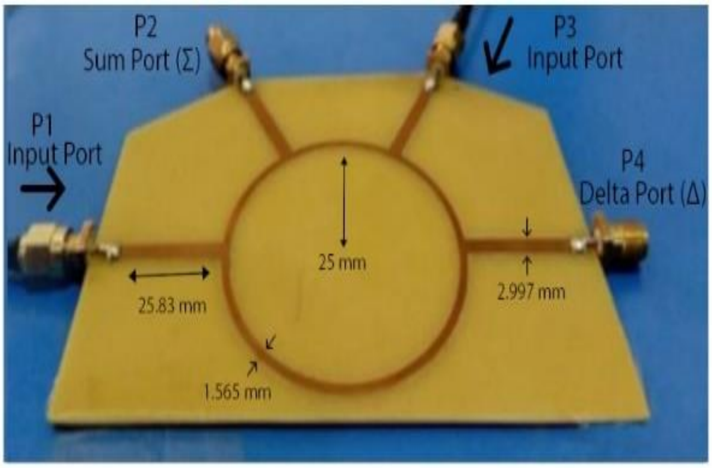


b) simulated and measured return loss (S11) versus frequency of the MPA array

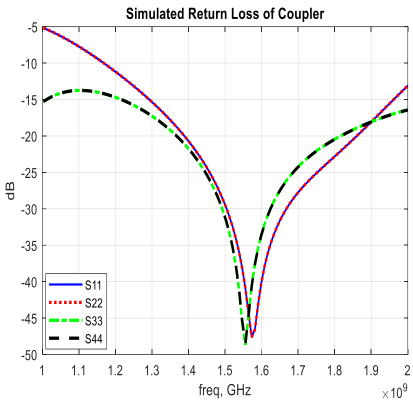
Fig. 2. Antenna array design

b) Coupler design

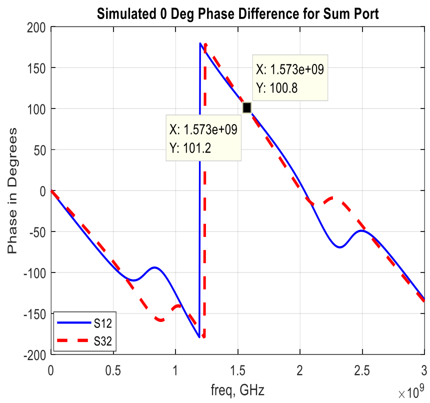
The 180^0 hybrid rat race (HRR) coupler or ring coupler, is a type of coupler used in RF/microwave devices, generally consisting of four ports. This component offers both in-phase (sum - ∑) and out-phase (difference - Δ) relationship at the designated output ports. For more details about ring coupler's usage and realization, readers are referred to [16, 17, 18]. Thus, in this work, the coupler has been used to obtain the Σ and the Δ of the input signal. The ring coupler has been designed at 1.575 GHz. The designed coupler using FR4 substrate is shown in Fig. 3 (a). The simulated return loss scattering parameters (S11, S22, S33, and S44) of all four ports are illustrated in Fig. 3 (b) which show that all ports resonate at central frequency with return loss approximately -47 dB. Moreover, Fig. 3 (c) and (d) shows the simulated coupler's phase differences for ∑ (0^0) and Δ ports (180^0), respectively. Furthermore, the same coupler was fabricated and characterized using vector network analyzer (VNA). The measured scattering parameters and phase differences are shown in Fig. 3 (e) to Fig. 3 (g), showing good correlation with the simulated results.



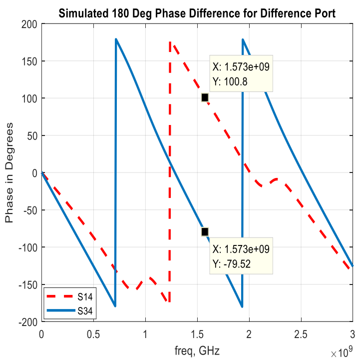
a). Fabricated coupler with design parameters



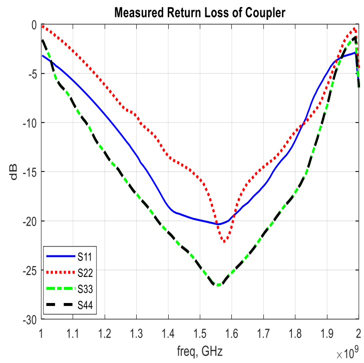
b). Simulated return loss of coupler.



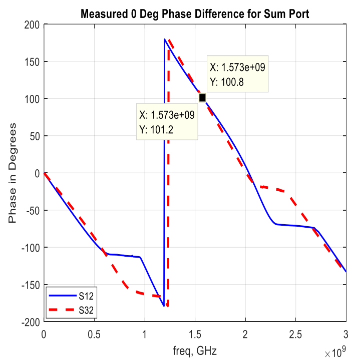
c). Simulated scattering (phase) parameters of ring coupler for ∑-port.



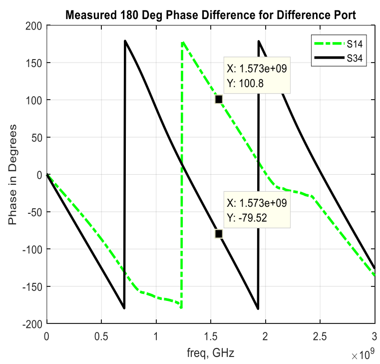
d). Simulated scattering (phase) parameters of ring coupler for Δ-port.



e). Measured return loss of coupler.



f). Measured scattering (phase) parameters of ring coupler for ∑-port.



g). Measured scattering (phase) parameters of ring coupler for Δ-port.

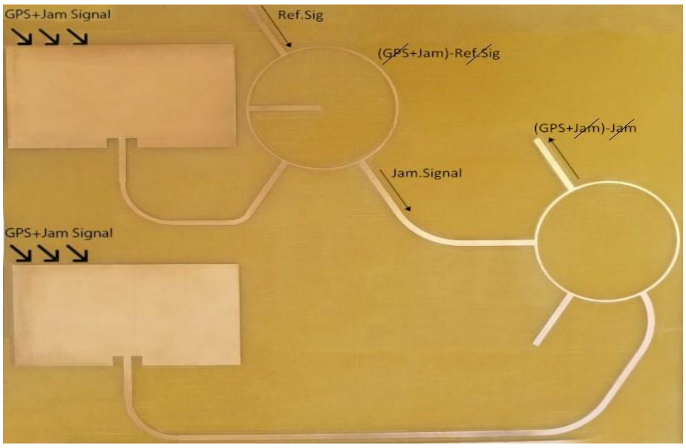
Fig. 3. Various simulated and measured results of the designed coupler.

4 Results and Discussions

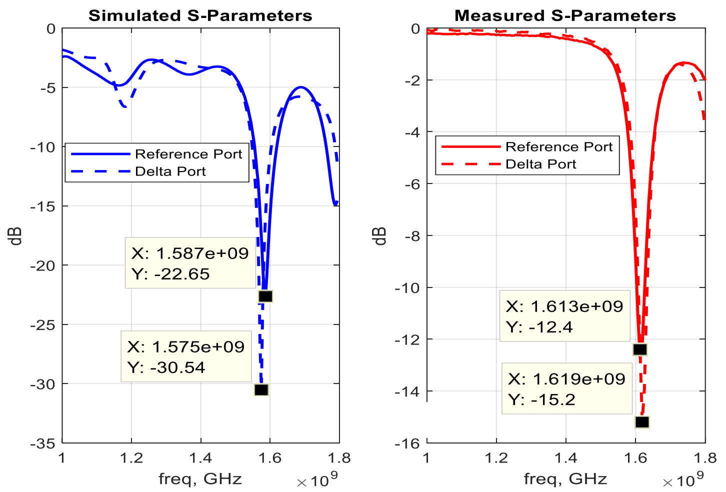
In this section, the results of the proposed design shown in Fig. 4 (a) are discussed. Fig. 4 (b) shows the simulated scattering parameters of the reference port of coupler 1 and delta (difference) port of coupler 2. Both desired ports resonate at 1.575 GHz and provide return loss of -22.65 dB for reference port and -30.54 dB for difference port. Similarly, Fig. 4 (b) also illustrates the measured return loss of the fabricated circuit which is slightly shifted to 1.615 GHz and provides return loss -12.4 dB for reference port and -15.2 dB for delta port. Furthermore, as shown in Fig. 5 (a), the fabricated circuit was measured in anechoic chamber to validate the performance for anti-jamming. In this regard, initially, a signal generator was used to generate L1 band signal on transmission side with transmission power (P_t) of 0 dBm (transmission antenna gain of 7dBi) and measured the received power (P_r) as -49.08 dBm on receiving side, as shown in Fig. 5 (b), by employing a single element patch antenna. This P_r is measured as a reference power to be achieved after employing the proposed circuit for both with and without jamming. Further, in this work, two experimental setups have been considered. In experiment one, we consider no any jamming source while in experiment two we consider jamming source and test the proposed system in anechoic chamber. Both experiments are discussed below with observed results.

First, the fabricated circuit was tested without employing any jamming source. In this regard the measurement setup shown in Fig. 6(a) was utilized. All the parameters of transmitter side are considered the same as defined earlier and all other ports were terminated using 50 Ω loads. The measured received power at port 4 of coupler 2 is -46.04 dBm, as illustrated in Fig. 6 (b), which is close to the required reference received power -49.08 dBm. Hence, the circuit is working normal when no jamming source is involved.

Next, the same circuit was measured in the presence of the jamming source. Whereas, in the transmission side, two horn antennas were excited with unequal input powers using 3dB attenuator (one antenna for GPS source signal with low transmission power and another antenna for jamming source signal with high transmission power). In this way, the desired circuit, deployed as receiving array, measured the received power as -52.94 dBm, as illustrated in Fig. 6 (b), which is again in good match to the original received reference signal i.e., -49.08 dBm. Thus, it is certain that the proposed circuit works appropriately and cancels out the high-power jamming signal and helps to avoid the GPS receiver to be saturated by jamming source.

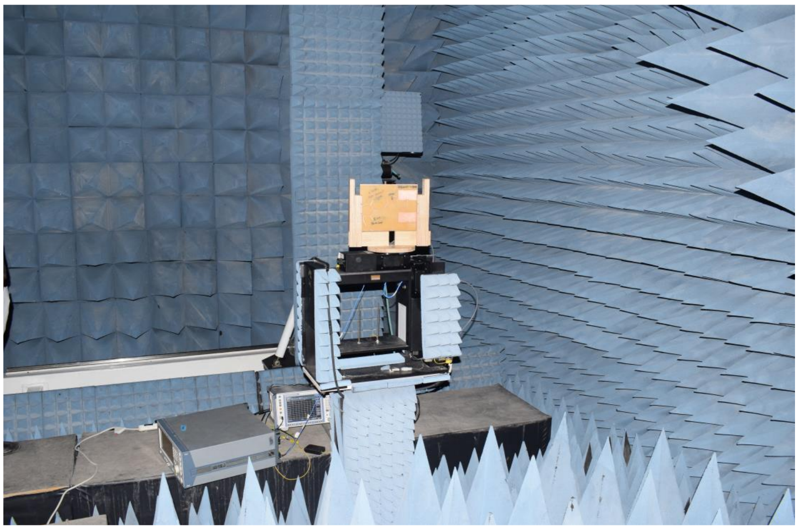


a). Fabricated circuit

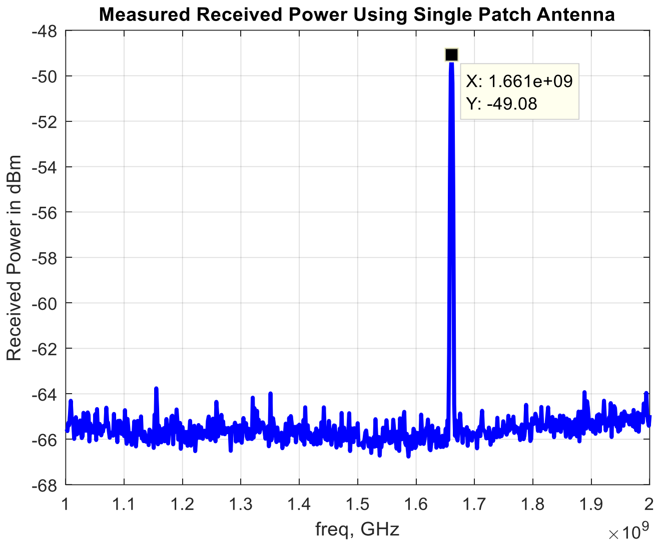


b). Simulated and measured return loss of designed circuit's reference (Coupler1) and delta ports (Coupler2).

Fig. 4. The proposed circuit design for GPS anti-jamming

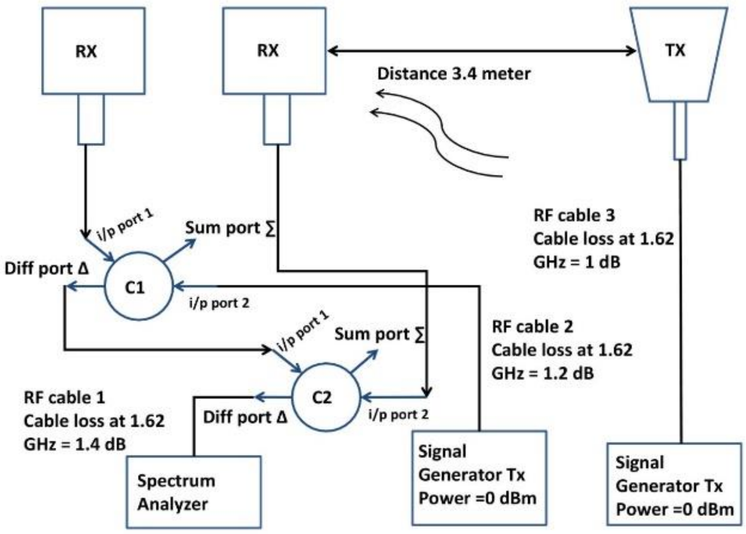


a). Measurement setup in anechoic chamber

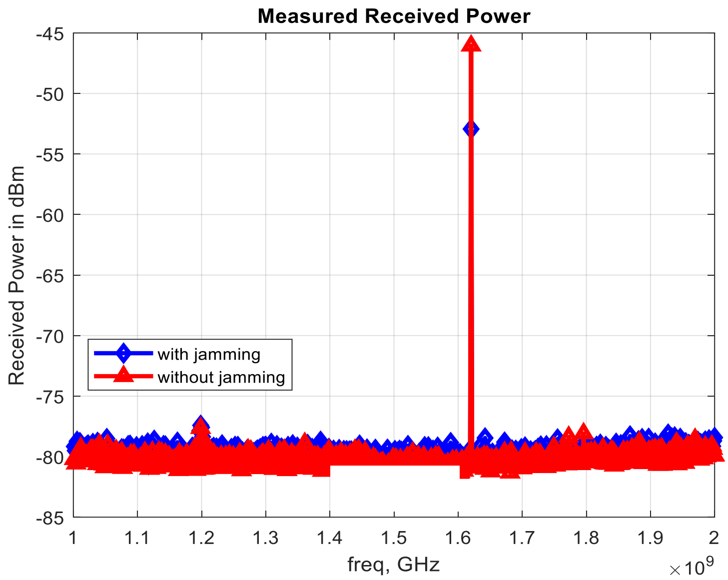


b). Received power using single patch antenna.

Fig. 5. Experimental testing



a). Experimental setup



b). Received measured power with (diamond) and without (triangle) jamming.

Fig. 6. Proposed circuit's testing

5 Conclusion

In this paper, a simple RF domain-based GPS anti-jamming approach has been proposed as an educational technology for learning and research. The proposed system, consisting of patch antennas array and couplers, is capable of working in both scenarios of with and without jamming source. It performs the anti-jamming without using any complex structure and saving the GPS receiver from going into the saturation due to high power of jamming source. The proposed method can be utilized to design anti-jamming systems for other GPS bands as well. Thus, the proposed approach has a great potential to be used for learning and research purpose for ICT students/researchers which will enable them to learn the basic principles of GPS anti-jamming in a simpler way.

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