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A Fault-Tolerant Batcher-Banyan Network for ATM Switching

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ABSTRACT

The Asynchronous Transfer Mode (ATM) is the transfer mode recommended for the B-ISDN by ITU. Batcher-Banyan networks have recently been adopted to construct internally non-blocking switching fabrics of future broadband networks. The Batcher-Banyan networks can provide only a unique path between each input-output pair of the network. Thus, a single fault in these network can destroy their functionality. Therefore, fault tolerance capability in these networks is an important consideration when designing ATM switches. In this paper, we propose a fault-tolerant Batcher-Banyan network for ATM switching. The proposed networks have the following features: high performance; fault-tolerance at each stage of the network; simple self-routing; and low cost.

1. INTRODUCTION

The Asynchronous Transfer Mode (ATM) is the recommended transport technique by ITU for the B-ISDN (Broadband Integrated Services Digital Network) which will provide communication services such as voice, video, and data. Many switches have been proposed to accommodate the ATM, which requires fast packet (cell) switching. Primary interest has focused on self-routing, space-switched architectures that are internally nonblocking. Banyan-based Multistage Interconnection Networks (MINs) have received considerable attention due to their favorable cost per performance ratio. They have features such as self-routing capabilities, low delay, cost-effectiveness, and suitability for VLSI implementation. Thus, the Banyan networks are suitable candidates for implementing ATM switches. One drawback of the Banyan networks is that they are internally blocking in the sense that two input cells destined for two different outputs may collide in one of the intermediate nodes. However, if all the input cells are first sorted based on their destination address and then routed through the Banyan network, the internal blocking problem can be avoided completely. Thus, to make a Banyan network internally nonblocking, the Banyan network is preceded by the sorting network (e.g. Batcher Bitonic sort network)[1]. The Starlite switch is the first switch fabric which uses the Batcher-Banyan network[2].

The Batcher-Banyan networks can provide only a unique path between each input-output pair of the network. Due to the large number of switching elements and links in Batcher-Banyan networks, any single fault in a switching element (SE) or a link may render some outputs unreachable from certain inputs. Therefore, fault tolerance capability in these networks is an important consideration when designing ATM switches[3-5].

To design a fault-tolerant ATM switch based on Batcher-Banyan network, both the sorting and routing networks must be fault-tolerant. In this paper, we present a fault-tolerant Batcher-Banyan network with the following features: high performance; fault-tolerance at each stage of the network; simple self-routing; and low cost.

The remaining part of this paper is organized as follows: In section 2, the Batcher-Banyan network is summarized. Section 3 discusses a common approach used to provide fault tolerant in Banyan based ATM switches. The proposed Batcher-Banyan network is presented in section 4. Network redundancy and terminal reliability analysis are presented in section 5 and Conclusions of paper are given in section 6.

2. BATCHER-BANYAN NETWORK

Batcher-Banyan Networks (BBNs) recently have been adopted to construct internally nonblocking switching fabrics of future ATM networks. The Batcher-Banyan network exploits the fact that a Banyan network is nonblocking if the active inputs are consecutive and the cells at these inputs are sorted based on their destination address[1]. Figure 1 shows the structure of a Batcher-Banyan network. The first segment consists of a Batcher Bitonic sort network which sorts the cells according to their destination address, followed by a shuffle exchange and a Banyan network which routes the cells.

Each node of the sort network as shown in figure 1 is a 2×2 SE which sorts the incoming cells in the order as indicated by the arrow shown. The sorting segment has $n \cdot (n+1)/2$ stages of SEs, where $n = \log_2 N$ and N is the network size, and each stage has $N/2$ SEs. The number of SEs in sorting network of size N is $(n^2+n) \cdot N/4$.

The routing network shown in figure 1 consists of n stages SEs and each stage has $N/2$ SEs. Banyan network supports distributed routing control; At stage i, where $0 \le i \le n-1$, bit d_i of the destination address, $d_{n-1}\, d_{n-2} \ldots d_2\, d_1\, d_0$ is used to route the packet. If $d_i = 0$, the packet is routed to the upper output port of the SE. If $d_i = 1$, the packet is routed to the lower output port of the SE.

Since the Batcher-Banyan network is a serial combination of the sorting and routing networks, it has $n \cdot (n+1)/2 + n$ stages of 2×2 SEs. The number of SEs in the Batcher-Banyan network of size N is $(n^2+n) \cdot N/4 + n \cdot N/2$. Since there is only one path between each input-output pair, any single fault in a switching element (SE) or a link will destroy the functionality of the network. Thus, the Batcher-Banyan network is non-fault-tolerant.

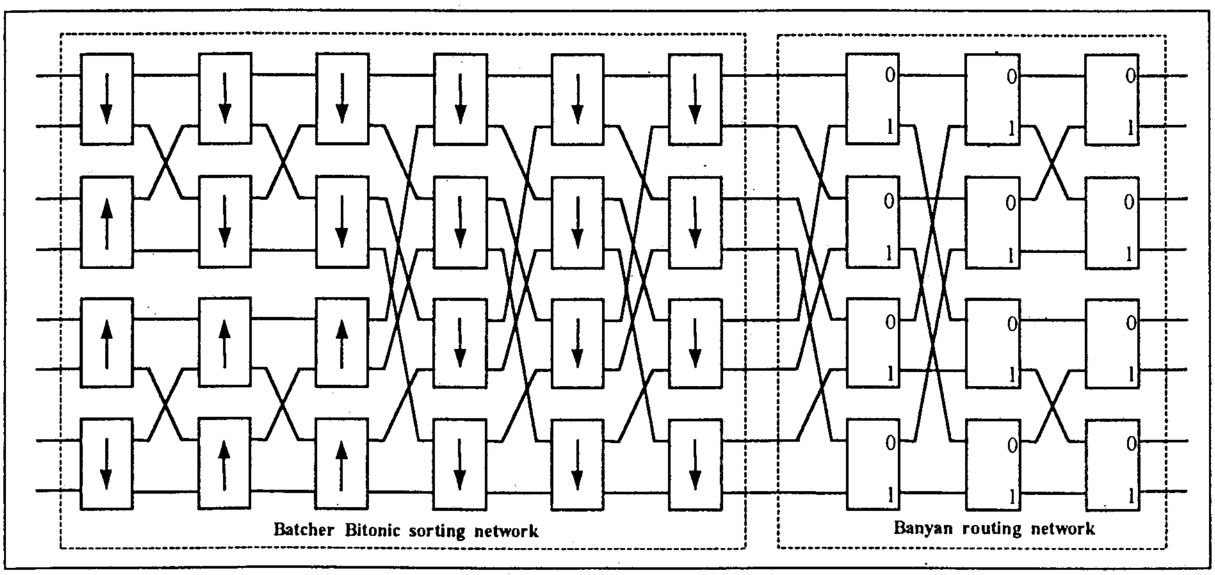

Figure 1. *Basic structure of a Batcher-Banyan network (N=8).*

3. FAULT TOLERANT BATCHER-BANYAN NETWORK

To design a fault-tolerant Batcher-Banyan network for ATM switching, both the Sorting Network (SN) and the Routing Network (RN) must be fault-tolerant. The use of hardware redundancy is a common approach used to provide fault-tolerance in Banyan based ATM switches[3]. In this scheme, the Batcher-Banyan network is augmented with extra hardware to provide multiple paths between each input and output ports. An example of this scheme is a parallel network where two or more networks (planes) are placed in parallel to each other. Two different approaches of implementing a parallel Batcher-Banyan networks are shown in Figure 2. Figure 2(a) shows a Parallel-Serial combination of Batcher-Banyan Network (PSBBN) which SNs and RNs are connected in parallel and the combination of them are connected in series and figure 2(b) shows a Serial-Parallel combination of Batcher-Banyan Network (SPBBN) which a pair of SN and RN are connected in series and a combination of these pairs are connected in parallel.

In the PSBBN, a fault free SN and RN are selected and the cells are transmitted through them. In the SPBBN, a pair of fault free SN and RN are selected for routing cell. Note that in both PSBBN and SPBBN a single fault in each SN or RN will destroy the functionality of the system. The terminal reliability's of these networks will be discussed in section 5.

4. PROPOSED FAULT TOLERANT BATCHER-BANYAN NETWORK

In this section, we present a fault-tolerant Batcher-Banyan network. To make the Batcher-Banyan network fault-tolerant, both the sorting and routing networks must be fault-tolerant. The basic idea of our proposed fault-tolerant Batcher-Banyan network (FTBBN) is embedding fault tolerance into SEs and links of basic BBN instead of using multiple networks. For this purpose, we use redundant links and the Modified 4×4 SEs (MSEs) which detect probable faults existing in a previous links or SEs and remove their (as shown in figure 3). Therefore, the FTBBN provides fault tolerance at each stage of the network.

The block diagram of each modified 4×4 SEs of the FTBBN for SN and RN is shown in figure 4. They consist of two basic 2×2 SEs and two Fault Detector and Remover (FDR) modules. The FDR modules placed at input side of MSE, detect the fault status of its inputs and remove any probable fault existing in previous links or SEs[6]. Figure 5 shows the functional operation of the FDR. If no fault exists, the FDR operates as a connecting interface as shown in figure 5(a). In the presence of fault, the FDR detects its faulty input link and restores the correct information from other link (safe input link).

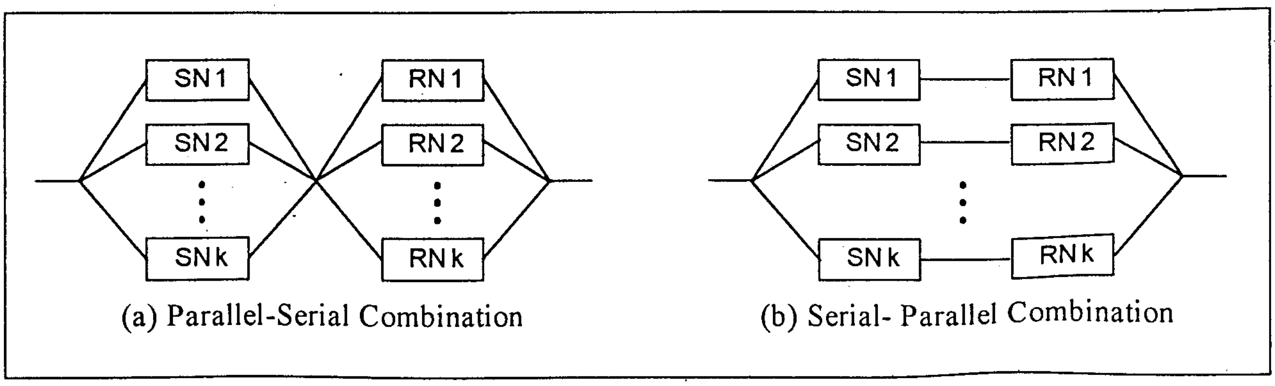

Figure 2. *Parallel Batcher-Banyan Networks.*

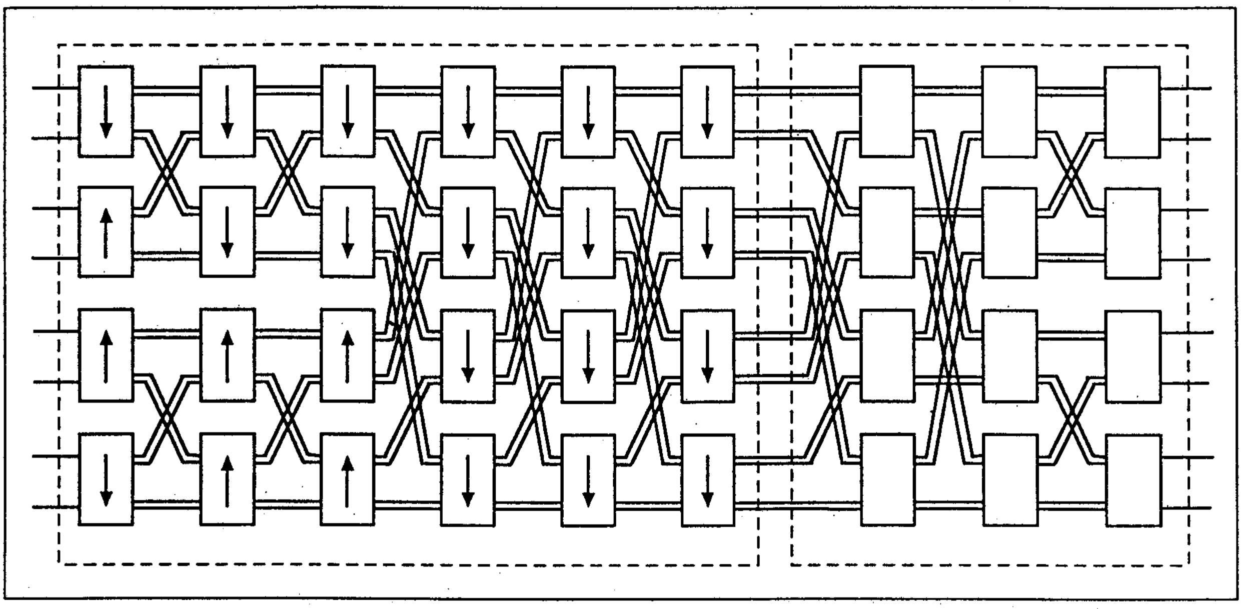

Figure 3. *Proposed Fault-Tolerant Batcher-Banyan network (N=8).*

Although the FTBBN has an additional delay due to use of modified 4×4 SEs instead of basic 2×2 SEs, this is comparable with other fault-tolerant schemes of ATM switching fabric, by considering the simple structure of modified 4×4 SEs[3-5]. If the proposed network has no fault, by considering the redundant links and modified 4×4 SE operation, the throughput can be increased.

5. NETWORK REDUNDANCY AND TERMINAL RELIABILITY

The redundancy graphs for the BBN, PSBBN, SPBBN, and FTBBN are shown in figure 6. Note that for parallel Batcher-Banyan network (PSBBN and SPBBN), we have only shown the case of 2 planes.

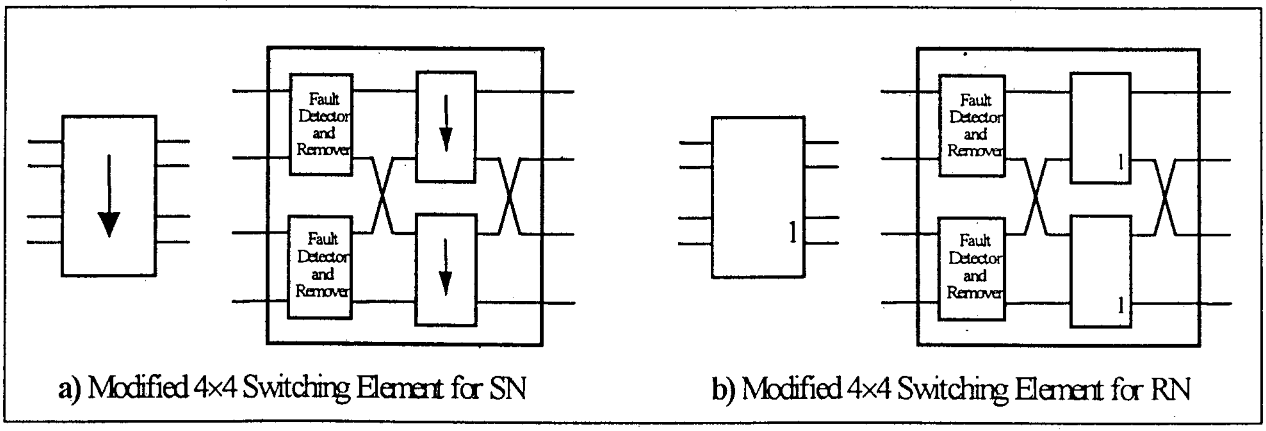

Figure 4. *The block diagram of modified* 4×4 *switching element.*

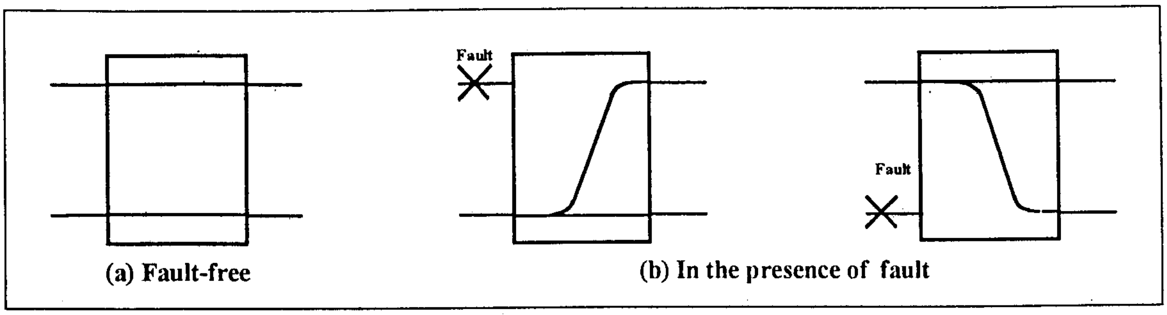

Figure 5. *Functional operation of fault detector and remover module.*

As shown in figure 6, BBN provides a single path between each input and output. The PSBBN provides two paths for SN and two paths for RN. The SPBBN provides two path between each input and output. Both PSBBN and SPBBN provide only a single path within a given SN and RN. In the case of proposed fault-tolerant Batcher-Banyan network, there are two paths provided in each stage of the network.

The number of Redundant Paths (RP) for each type of Batcher-Banyan networks are:

$RP_{BBN} = 1$
$RP_{PSBBN} = k^2$
$RP_{SPBBN} = k$
$RP_{FTBBN} = 2^{n(n+1)/2+n}$

where k is the number of planes in PSBBN and SPBBN. As an example, if $k = 2$ and $N = 16$ ($n = 4$), then $RP_{BBN} = 1$; $RP_{PSBBN} = 4$; $RP_{SPBBN} = 2$; and $RP_{FTBBN} = 1.64*10^4$. This example demonstrates the high fault-tolerance provided by the proposed fault-tolerant Batcher-Banyan network. In the proposed network, the number of redundant paths increases as n increases.

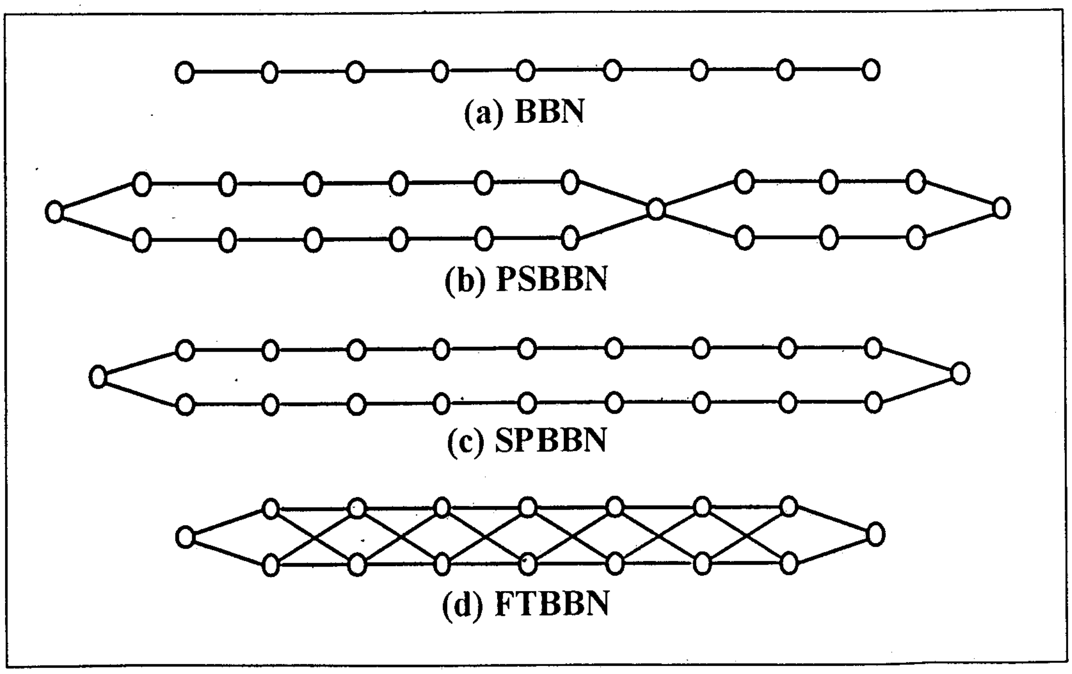

Figure 6. Redundancy Graphs for N = 8.

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Expression for the Terminal Reliability (TR) for the BBN, PSBBN, SPBBN, and FTBBN can be derived by studying the series and parallel relationship of the SEs in the redundancy graphs shown in figure 6[3][7]. For PSBBN and SPBBN, we assume that k = 2.

$$TR_{BBN} = R_{se}^{n(n+1)/2+n}$$
$$TR_{PSBBN} = R_{demux} * [2R_{se}^{n(n+1)/2} - R_{se}^{n(n+1)}] * R_{se} * [2R_{se}^{n} - R_{se}^{n/2}] * R_{mux}$$
$$TR_{SPBBN} = R_{demux} * [2R_{se}^{n(n+1)/2+n} - R_{se}^{n(n+1)+2n}] * R_{mux}$$
$$TR_{FTBBN} = [2R_{mse}^{1/2} - R_{mse}]^{[n(n+1)/2+n]}$$

where R_{se}, R_{mse}, R_{demux}, and R_{mux} are the reliability's of the basic 2X2 SE, modified 4X4 SE of the FTBBN, demultiplexer, and multiplexer, respectively. To compare the reliability's of the four networks, we have assumed the following values for reliability's:

$R_{se} = 0.95$,
$R_{demux} = R_{mux} = 0.98$,

Since the MSE consists of two SEs and two FDRs, the reliability of the MSE is:

$$R_{mse} = R_{se}^2 * R_{fdr}^2$$

where if $R_{fdr} = 0.98$ then $R_{mse} = 0.87$.

Figure 8 shows the terminal reliability of the four networks. It is obvious that our proposed fault-tolerant Batcher-Banyan network has a very high reliability as compared to other considered networks.

6. CONCLUSIONS

In this paper we have presented a fault-tolerant Batcher-Banyan network. The proposed network provides fault-tolerance in each stage of the network. It has an additional delay due to use of modified 4×4 SEs instead of basic 2×2 SEs, this is comparable with other fault-tolerant schemes of ATM switching fabric, by considering

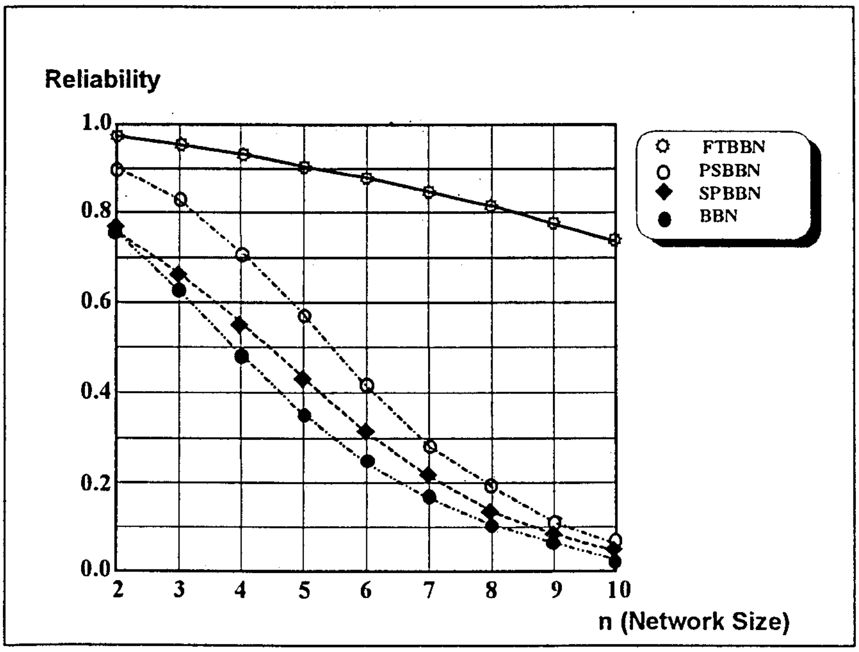

Figure 8. *Terminal Reliability versus Network Size.*

the simple structure of modified 4×4 SEs. If the proposed network has no fault, the throughput can be increased. In the proposed network, there are two paths provided in each stage of the network and the number of redundant paths increases as n increases. The terminal reliability analysis shows that the proposed network has very high reliability as compared to other networks considered.

7. REFERENCES

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