Recent advances in the design of matrix amplifiers*

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Contents: Recent developmental trends in the field of wide-band matrix amplifiers are discussed using a 6 GHz - 18 GHz monolithic module as a representative example. Employing only four MESFET functions, the unit achieves a gain of $G = 16.5 \text{ dB} \pm 0.35 \text{ dB}$ at a maximum return loss of $RL = -10 \text{ dB}$ across the 6 GHz - 18 GHz frequency band. Even at gain compression levels of 10 dB, the worst harmonic output power does not exceed $P(3f_0) = -13.2 \text{ dBc}$. The monolithic chip's dimensions are $1.8 \times 2.75 \times 0.115 \text{ mm}$.

Introduction

The amplification obtained from two or more active devices, such as electron tubes or transistors, may be classified as multiplicative or additive, depending on whether the overall gain is proportional to the product of the gain supplied by, or the sum of the powers contributed by the individual active components. Today's majority of amplifiers makes use of the multiplicative process through cascading of modules. The most well-known exception is the distributed or traveling-wave amplifier whose mechanism is based on the additive principle as it was first proposed by W. S. Percival in 1935. [1] However, Percival's invention did not go into active use until after E. L. Ginzton et al., published their analysis of the distributed amplifier in 1948. [2] First experimental results verifying the theoretical predictions were reported shortly thereafter [3, 4].

Percival's concept was based on the idea of neutralizing the parasitic interelectrode capacitances of the then-used electron tubes by linking them with inductances to form artificial transmission lines. This was done in such a way that a chainlike network (Kettenverstärker) resulted that added the active devices' transconductances, thus forming the first additive amplifier. Obviously, due to the additive nature of this principle, amplification could be achieved at frequencies at which the amplification of each individual active element was even smaller than $G = 0 \text{ dB}$.

With the emergence of the transistor and the ever-increasing pursuit of larger gain bandwidth products, the distributed amplifier has become the leading candidate for ultra-wideband amplification at microwave frequencies. Since the early experiments in the late forties, the development of the traveling-wave amplifier has come a long way. Today, its performance in bandwidth at reasonable gains has been advanced to millimeter-wave frequencies [5, 6]. Very recently, the performance of a 5 GHz - 60 GHz monolithic amplifier module was reported, which achieved $G = 8.0 \text{ dB} \pm 1 \text{ dB}$ of gain by employing ten FET functions in five cascade arrangements, employing high electron mobility transistors (HEMTs) [7].

Since the original concept of the distributed amplifier was patented in 1937, few modifications of this circuit have surfaced. However, two variations of technical importance have emerged as recently as 1984. In the first variation, the common source field-effect transistor (FET) is replaced by two FETs in cascode configuration yielding somewhat higher gains and significantly increasing the unit's reverse isolation [8]. In the second modification, two distributed amplifier...
circuits share a common drain line resulting in two input ports that receive their input signal through a power divider. [9] In this case, the output power is doubled with no change in gain. In this paper, we plan to report on our experience made with a new type of amplifier that combines the additive and the multiplicative principles in one and the same module. This amplifier, which consists of a rectangular array of active devices, MESFETs in our case, has been given the name matrix amplifier. Conceived in 1985, its design and performance were first discussed in 1987. [10, 11] The matrix amplifier adds a new dimension to the family of additive amplifiers, in the form of one or more rows of active devices. In its most general form, the amplifier consists of a rectangular array of \( m \) rows and \( n \) columns of transistors, linking each column to the next by either inductors or transmission-line elements, composing a lattice of circuit elements. For \( m \) active rows or tiers, there are \( 2m \) idle ports that need to be terminated. This new type of amplifier was found to have performance advantages in regard to gain, input and output VSWR, noise figure, as well as reverse isolation. A detailed description of the circuit and its theory can be found in the literature [11, 12].

2 The circuit

To this date, three circuit versions, the \( 2 \times 4 \), the \( 3 \times 3 \), and the \( 2 \times 2 \) matrix amplifier, have been realized in either hybrid or monolithic technology [11-17].

Fig. 1. Schematic of the \( 2 \times 2 \) Matrix Amplifier

Fig. 2. Computed Performance Parameters of the \( 2 \times 2 \) Matrix Amplifier Using the MESFETs Characterized in Figure 5

Fig. 3. Photograph of the Experimental Amplifier Module

Since ample treatment — theoretical as well as experimental — has been given in the above referenced literature, we limit our discussion of the circuit to that of the most recent and the most fundamental representative of the family, the \( 2 \times 2 \) matrix amplifier. A complete and representative schematic of the circuit is shown in Fig. 1. Notably, the network in Fig. 1 is that of an experimentally proven 6 GHz to 18 GHz monolithic matrix amplifier which includes such important components as an input and output matching network, as well as transformation elements \( (T_{c1} \text{ and } T_{c3}) \) at the transistors' drain ports. In addition, and in contrast to earlier developments, we have chosen to terminate two idle ports, i.e., the input end of the centerline and the drainline with purely reactive transmission line elements \( (T_{c1} \text{ and } T_{c3}) \). Such measure allows the amplifier to be operated by means of an extremely simple self-biasing network energized by a single voltage \( (V_{bias}) \). As a result, only two of the four idle ports are terminated into power dissipating loads.