Letters

Binary Power-Divider Design Approach

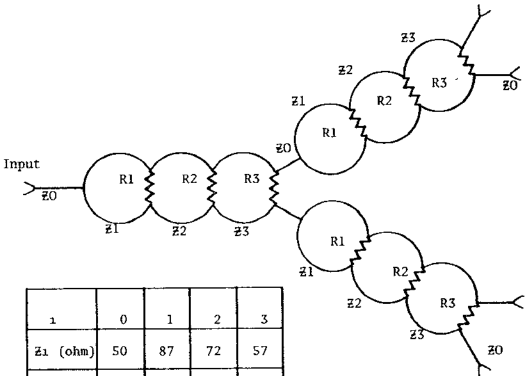
HARRY F. CHAPELL

Abstract—**Utilizing all sections of binary power dividers in a single transformer yields a reduced circuit length for a specified electrical performance.**

Yee *et al.* have presented tables for a wide range of N-way three-dimensional step-transformer power dividers [1]. This short paper suggests a method of achieving equivalent performance in two-dimensional binary power dividers.

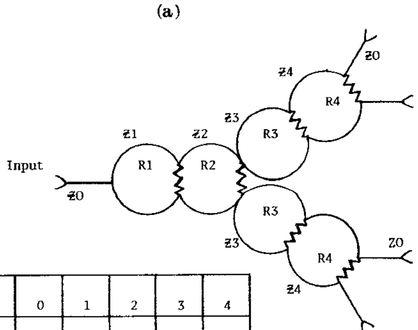
Two design examples are given to illustrate the technique.

Example 1: A four-way divider is required to cover 1–2.6 GHz. A 0.9–2.7-GHz 1.2/1 maximum-VSWR design bandwidth was chosen to allow for production tolerances. If cascaded, randomly spaced two-way dividers (whose terminals are matched to 50 Ω) are used, each divider will require a three-section step transformer. The overall circuit length will be at least 1.5 wavelengths. On the other hand, a four-section transformer with a four-to-one impedance ratio has a theoretical VSWR of 1.09/1 maximum over a 0.9–2.7-GHz frequency range. The total circuit length can be as short as one wavelength, which represents a 30-percent reduction in size and insertion loss. Impedance values for the two approaches are shown in Fig. 1. The transmission-line impedances were obtained from tables of step-impedance transformers [1]. For a three-to-one bandwidth ratio, the normalized step admittances from the tables are 0.2973, 0.4102, 0.6094, and 0.8409. The first two are doubled to account for the effective paralleling of the lines in the circuit shown in Fig. 1(b), yielding 0.5946 and 0.8204. After taking reciprocals to obtain normalized impedance and after denormalizing by multiplying by 50 Ω, the values shown in Fig. 1(b) were obtained. Although Yee *et al.* give normalized values for the shunt resistors, which were used to obtain the values for Fig. 1(a), the tables are not applicable to the circuit of Fig. 1(b). Shunt-resistor values were obtained empirically for this case. Production dividers constructed from the four transformer step design provided a comfortable margin against specification limits of 1.45/1 maximum input and output VSWR, 1-dB-maximum insertion loss (excluding coupling loss), and 20-dB-minimum isolation between outputs.



i	0	1	2	3
Zi (ohm)	50	87	72	57
Ri (ohm)	-	103	203	407

(a)



i	0	1	2	3	4
Zi (ohm)	50	84	61	82	69
Ri (ohm)	-	125	200	125	200

(b)

Fig. 1. Impedance values for 0.9–2.7-GHz 4-way dividers. (a) Cascaded 3 transformer-section 2-way dividers. (b) 4 transformer-section 4-way dividers.

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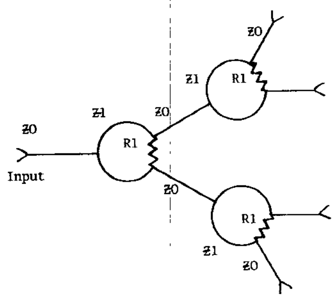
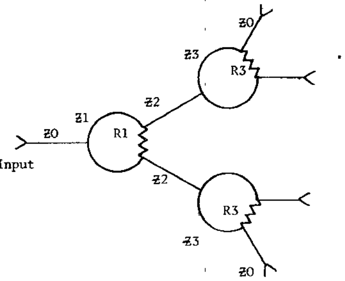


i	0	1
Zi (ohm)	50	71
Ri (ohm)	--	100

Z1 λ/4 long

(a)



i	0	1	2	3
Zi (ohm)	50	84	50	60
Ri (ohm)	-	100	-	100

Z1, Z2, and Z3 each λ/4 long

(b)

Fig. 2. Impedance values for 3.7–4.2-GHz 4-way dividers. (a) Cascaded single-section 2-way dividers. (b) 3 transformer-section 4-way dividers.

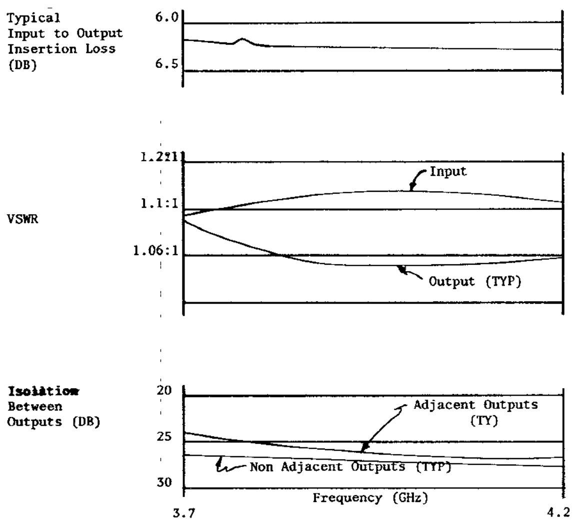


Fig. 3. Three transformer-section 4-way power dividers.

In fairness, it should be noted that, if the three-section two-way dividers are cascaded with zero line length between them, the VSWR of the cascade will be better than the worst-case condition of random length between the dividers. However, at higher frequencies, for physical realizability, a length of line between the cascaded dividers is desirable. The approach suggested in this short paper can still be applied to advantage.

Example 2: A four-way divider is required for 3.7–4.2 GHz. A three-section 4-to-1 impedance-ratio prototype was selected. With a normalized bandwidth of 0.2, the theoretical maximum VSWR is 1.02/1. With cascaded single-section transformer dividers, the VSWR over the same bandwidth would vary between 1.03/1 (with no length between the dividers), 1.24/1 maximum (with a quarter-wavelength between the dividers), and 1.12/1 maximum (with a half-wavelength between the dividers).

Fig. 2 shows impedance values for the two approaches. Fig. 3 gives typical performance of the three transformer-section design.

Summarizing, a significant improvement in the performance of a set of cascaded power dividers can be achieved by considering the entire chain as a multistep transformer, rather than designing each divider to be matched to 50 Ω at its input and output.

REFERENCES

[1] H. Yee, F. Chang, and N. Audeh, "A study of wideband *N*-way power dividers," Univ. Ala. Res. Inst., ASTIA AD693290, July 1969

A Coolable Degenerate Parametric Amplifier for Millimeter Waves

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***Abstract*—The first 20-K-cooled degenerate parametric amplifier for 46 GHz is described. New 20-K-cooled circulators and Schottky-barrier varactors are used. Its noise temperature of less than 60 K means almost an order-of-magnitude improvement over previous uncooled amplifiers.**

I. INTRODUCTION

Operational parametric amplifiers with signal frequencies up to 60 GHz and SSB noise temperatures in the order of 600 K have been reported previously [1]. This letter describes several new developments in the millimeter-wave range, which lead to a 20-K-cooled degenerate amplifier with a very low noise temperature. One of the unresolved problems in the field of cooled amplifiers was the lack of coolable circulators. Recently, a way has been found to construct broad-band-type junction circulators for the millimeter frequency range. At 46 GHz an insertion loss of 0.7 dB and an isolation of more than 20 dB over 3.5 GHz was achieved with single junction circulators when cooled down to 16 K [2].

II. VARACTOR

Theoretical and experimental studies were performed in order to determine the optimum diameter of the platinum–gallium arsenide Schottky-barrier junctions used in the amplifier. It turned out that a diameter of 2 μm constituted the best compromise between the requirements for low pump power, broad bandwith, low noise temperature, and reproducible and mechanically strong contacts. One problem which arises when the tiny gold-plated platinum dots are contacted with a pointed whisker is the stray capacitance of its tapered section against the grounded substrate. This capacitance C_s is shunting the junction capacitance C_j and the loss resistance r in the n-type epilayer, as can be seen from the sketch of the contacted junctions and its simplified equivalent circuit in Fig. 1(a) and (b), respectively. The value of C_s was determined using the method of images and curvilinear squares; both methods yielded in close agreement a value for C_s that is 10 percent of the junction capacitance C_{j0}, or approximately 0.001 ρF. The use of 1-μm junctions instead of 2-μm junctions would roughly quadruple the ratio C_s/C_{j0} assuming about the same whisker taper of 10°; this taper can hardly be made smaller—at least not in the area close to the junction which is mainly responsible for C_s. The large ratio C_s/C_{j0} of 1-μm junctions would result in a sizable shunt for the negative resistance appearing across junction capacitance C_j in Fig. 1(b). This, in turn, means a degradation in noise temperature and bandwidth as compared with the 2-μm junctions. The 2-μm diodes, however, have the disadvantage of requiring much more pump power because of their larger average junction capacitance.

In order to obtain a mechanically strong and yet elastic contact a very short whisker of only 5 mil length is used which has a 90° bend.

Fig. 2 shows the *I–V* curves of a typical 2-μm junction measured at room temperature and at 16 K. From these curves a strong increase of the slope parameter η in the current-voltage equation $I = I_0[\exp(-qV/\eta kT) - 1]$ is evident (η = 1.17 at 300 K; η = 8 at 16 K). However, the dc resistance R_0 extrapolated from the high forward-current region does not seem to change noticeably with temperature (R_0 = 7.5 Ω at 300 K and at 16 K). This indicates that the junctions are well suited for varactor applications at cryogenic temperatures. De Loach-type resonance measurements at room temperature around the midband signal frequency f_s = 46 GHz, and subsequent more precise reflection measurements at a fixed frequency of 46 GHz under varying bias voltage [3]–[5], indicated a cutoff frequency $f_c \geq 800$ GHz at zero bias voltage.

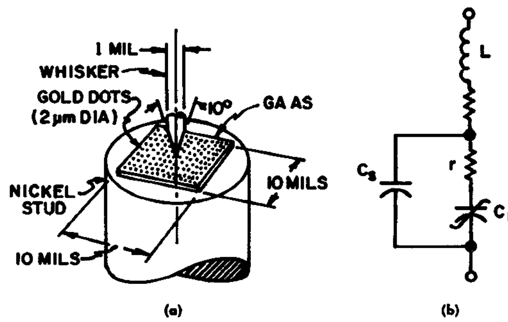

Fig. 1. (a) Physical diode structure close to junction. (b) Equivalent circuit of structure in (a).

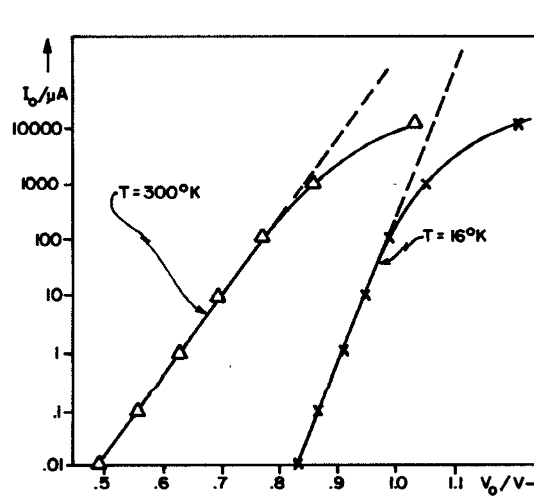

Fig. 2. *I–V* curves of Schottky-barrier diodes used as varactors (platinum–gallium arsenide). Epilayer donor concentration $N_D = 2 \times 10^{17}/cm^3$. *T* is the physical temperature.

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