PROTOTYPE NETWORKS IN BROADBAND PARAMETRIC AMPLIFIER SYNTHESIS

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ABSTRACT

Results of a study of prototype networks suitable for use in a generalized DeJager single tuned idler nondegenerate parametric amplifier synthesis are summarized. N'th order lumped Butterworth and Chebyshev networks including Darlington D-sections, redundant and nonredundant commensurate line structures and mixed lumped distributed configurations are considered.

Lumped Element Synthesis

The relations derived by DeJager facilitate the replacement of a pumped varactor diode and its associated tuning network with the last two resonators and negative resistive load of a bandpass ladder network. This network, hereafter referred to as the prototype network, has provided a basis for a number of synthesis strategies [1,2,3,4]. In contrast to most other design methods the resonator closest to the active load consists of a negative capacitor and inductor. It has been previously shown that an optimal choice of idler frequency may be made only after specification of amplifier gain characteristics [5]. The solution obtained through application of this principle to n'th order Butterworth and Chebyshev networks including Darlington D-sections permits a more satisfactory explanation of the seemingly anomalous results which have been obtained employing the more usual odd order networks [6]. In contrast to the approach of Yamaguchi and Takei, the idler frequency and prototype network have been simultaneously optimized using a Powell optimization subroutine. Equations 27 and 31 of Yamaguchi and Takei have been generalized so that an apriori choice of idler frequency is no longer required. The expressions derived take the following form:

$$\alpha_3\left[\frac{d_2^{\,2}}{\omega_{20}^{\,4}C_0^{\,2}R_D^{\,2}}\right]\omega_c^{\,3}+\alpha_2\left[\frac{d_2}{\omega_{20}^{\,2}C_0R_D}\right]\omega_c^{\,2}+\alpha_1\omega_c=\frac{2\omega_{10}\gamma^2}{d_1\omega_{20}C_0R_D}$$

where: γ, C_0, R_D are diode parameters

ω_{10} is the signal band center frequency

ω_{20} is the idler band center frequency

$\omega_{10}<\omega_D<\omega_{20}$

$$d_1=\frac{\omega_{20}^{\,2}-\omega_{10}^{\,2}}{\omega_{20}^{\,2}-\omega_D^{\,2}}\quad,\quad d_2=\frac{\omega_{20}^{\,2}-\omega_{10}^{\,2}}{\omega_D^{\,2}-\omega_{10}^{\,2}}$$

$\alpha_1\ \alpha_2\ \alpha_3$ are given in Yamaguchi and Takei for both Butterworth and Chebyshev response.

Optimum values of ω_{20} and ω_D must be found such that ω_c is maximized. Calculated bandwidth versus normalized idler frequency for Butterworth response and bandwidth versus dB ripple are respectively represented in figures 1 and 2. (Diode characteristics : C_0=1F; R_D=0.008333Ω; γ=0.25; ω_{10}=1RPS; $\tilde{Q}_1$=30.) In both cases the parameter N represents the number of sections in the prototype network; a negative sign indicates the presence of the aforementioned D-section. In contrast to earlier publications Chebyshev prototype networks which include a Darlington D-section display steadily increasing bandwidth as passband ripple is increased. The optimum idler frequency is consistently greater than that of the simpler prototype networks and bandwidth versus idler frequency is much flatter. It is interesting to note that at the conjunctures of the curves for N=±3 and N=±5 in figure 1 the D-sections become degenerate. A four section parametric amplifier prototype with a maximum gain of 15dB, passband ripple of 0.25 dB and 26.2% bandwidth is scematically represented in figure 3. Element values are given in Table I.

Commensurate Line Synthesis

The transition from lumped prototype to distributed realization has often been achieved in practice through the use of approximate equivalences. Alternately, a two step design process in which the varactor diode is first resonated with distributed elements after which transformer elements are added to satisfy subsystem impedance level requirements has been used. The possibly deleterious effect of the transforming sections on amplifier bandpass characteristics has received relatively little attention in the microwave literature. Extension of the lumped element synthesis to commensurate line structures has permitted simultaneous realization of bandwidth and impedance level requirements. The optimum quarter wave line synthesis developed by Horton and Wenzel has been modified to include a negative resistive termination, a negative S-plane shunt inductor and an S-plane series capacitor in a manner analogous to that employed for lumped elements [7]. A representative S-plane prototype is shown in figure 4a. A computer program has been written which implements this strategy [8]. Nonredundant structures are rarely found suitable since the transformation achieved is fixed by the element extraction order. Redundant structures, however, provide great freedom in the realization of required impedance levels. Structural constraints and the question of redundancy will be reviewed within the context of a number of examples.

Lumped Distributed Synthesis

The replacement of the end resonators of the prototype network with S-plane elements is limited in applicability to narrow band amplifiers. A more satisfactory prototype consisting of the lumped DeJager end section combined with a commensurate line structure has been the object of further numerical investigation. A direct synthesis for a mixed topology of this type has not been presented in the literature to date. Figure 4b portrays an appropriate mixed element prototype. Nevertheless a reasonable initial choice of element values followed by computer optimization provides excellent correspondence with the passband response achieved when using a purely commensurate line or lumped element synthesis. In figures 5 and 6 the transmission gain and phase of a commensurate line network and a mixed network are presented (curves 1 and 2) for comparison. These results have been obtained through application of a modified version of CANOPT [9]. Element values for the S-plane prototype of figure 4a and the lumped distributed prototype of figure 4b are given in Table II.

Further Prototype Network Synthesis Considerations

The three classes of prototype network described above are all lossless in nature and are thereby limited in their usefulness to the lower microwave region. The original derivation of the DeJager end section included a series resistance which was later omitted to simplify the prototype network synthesis. Yamaguchi and Takei laid the theoretical basis for the development of a suitable lumped element synthesis [10]. Egami has recently published extensive tables for a lossy three resonator synthesis based on numerical calculations [11]. An alternate solution based on an approximate n'th order lossy synthesis akin to that developed by Chan and Kuh for Tunnel Diode Amplifiers constitutes the final area to be reported [12]. The synthesis results are further refined by means of computer optimization. Examples of Maximally Flat and Equal Ripple response for varying degrees of loss will be presented.

References

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Table I

Parametric Amplifier D-Section Prototype Element Values

RGEN 1.000	RNEG -.3969	RLOAD 1.000	N 1.589
L1 -0.05849	L2 0.5774	L3 0.06428	L4 1.676
C1 -17.10	C2 1.732	C3 15.560	C4 0.5967
L5 0.6894	L6 0.6894	L7 0.08182	L8 0.05637
CA 12.22	CB 1.451	M1 0.6894	M2 -0.06791

Table II

Parametric Amplifier S-Plane and Lumped-Distributed Prototype Element Values

	S-Plane	Lumped-Distributed
RGEN	1.000	1.000
RNEG	-1.000	-1.000
RLOAD	1.000	1.000
N	3.744	3.744
Z1	0.02972	0.04231
Z2	0.002638	0.006356
Z3	0.1332	0.1891
Z4	2.465	-
Z5	-0.12930	-
L2	-	0.5475
C2	-	0.04740
L1	-	-0.05481
C1	-	-0.4590

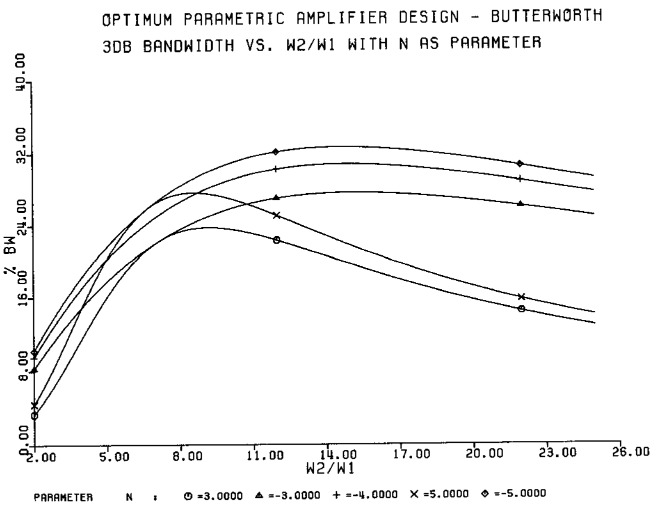


Figure 1

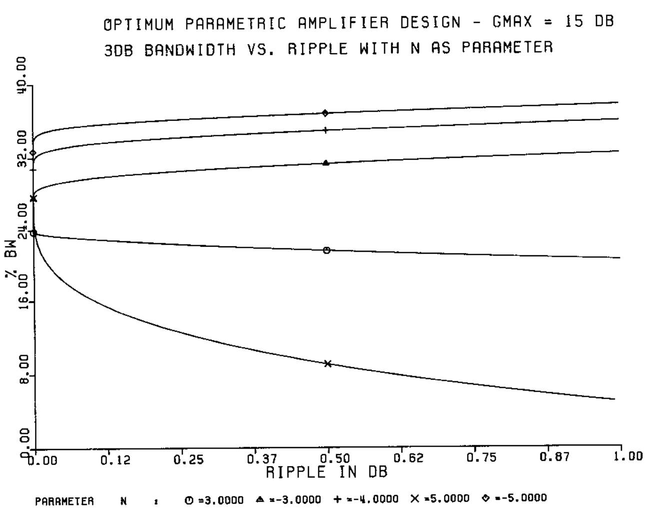
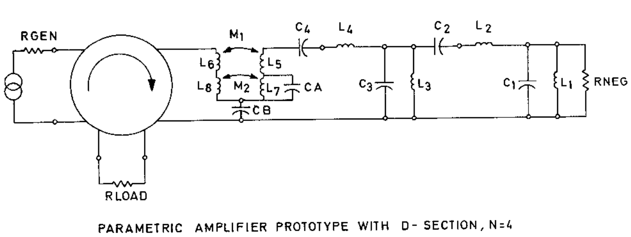


Figure 2



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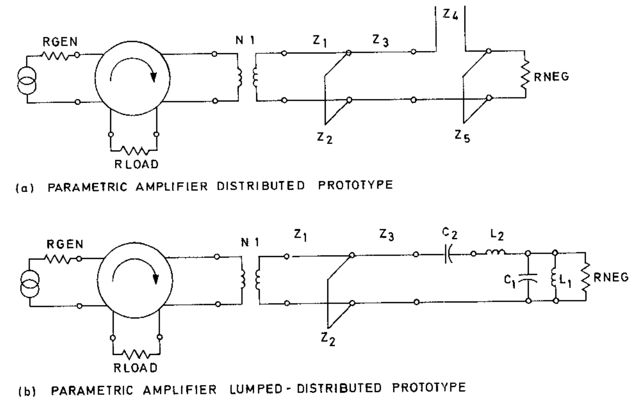

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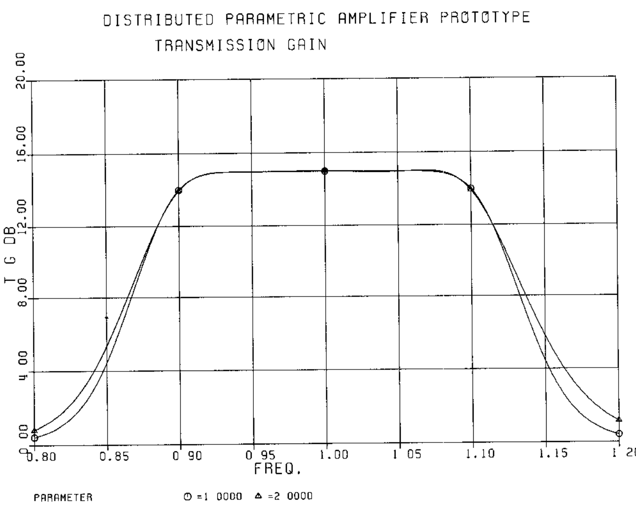

Figure 5

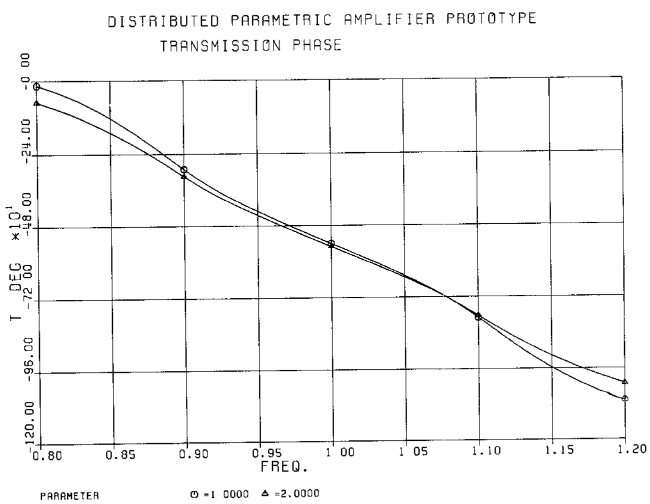

Figure 6