

SELF-EQUALIZED DISTRIBUTED AMPLIFIER FOR WIDE BAND OPTICAL TRANSCEIVERS

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Abstract A novel technique for a self-equalized distributed amplifier is presented by showing the analogy between transversal filters and distributed amplifier topologies. The appropriate delay and gain coefficients of amplifier circuit are obtained by a Fourier expansion of the raised cosine spectrum in the frequency range of 0-40GHz.

Key Words Distributed Amplifier, Transversal Filter, Raised Cosine

چکیده در این مقاله یک روش جدید برای طراحی تقویت کننده گسترده با فاز خطی ارائه می شود. این روش بر مبنای شباهت بین توپولوژی فیلتر دیجیتال ترانسورسال و تقویت کننده گسترده می باشد. بر مبنای این توپولوژی گین هر طبقه از تقویت کننده و مقدار تاخیر بین دو طبقه مجاور با استفاده از بسط فوری فیلتر Raise Cosine طوری تعیین می شود که در فاصله فرکانسی 0-40 GHz تقویت کننده دارای مشخصه فاز خطی خواسته شده باشد. با شبیه سازی پاسخ فرکانسی این تقویت کننده خطی بودن فاز این تقویت کننده نشان داده می شود.

1. INTRODUCTION

Conventional optical-fiber receiver design requires a front-end preamplifier followed by an equalizer circuit which is a pulse shaping filter improving the overall frequency performance and minimizing intersymbol interference. This arrangement adds complexity to the design of receiver and increases production and packing cost. An alternative method is to tailor the preamplifier response so that it matches the response of the required filtering transfer function. In this method, pulse shaping/filtering is embedded in the preamplifier itself, which consequently reduces the number of circuit interconnections and improves circuit and system reliability [1]. Jutzi was the first to demonstrate the use of distributed amplifier as an active transversal filter for low microwave frequencies [2]. Although the concept of distributed amplifier is rather old but its application for high-speed data is nowadays

increasing [3-4]. Recently, a distributed amplifier has been conceptually demonstrated as an active pulse-shaping network by setting different stage gains while equalizing the differential delays of all amplifier stages. In this method, a desired transfer function response was obtained by means of additional delay line in the gate artificial transmission line [5].

In this paper a design technique is presented for a distributed amplifier using a 40GHz P-HEMT coplanar waveguide configuration with 100% raised cosine shape.

2. AMPLIFIER DESIGN

Conventional distributed amplifiers for optical transceiver applications consist of symmetrical input and output artificial lines constructed by microstrip or coplanar waveguide and the parasitic

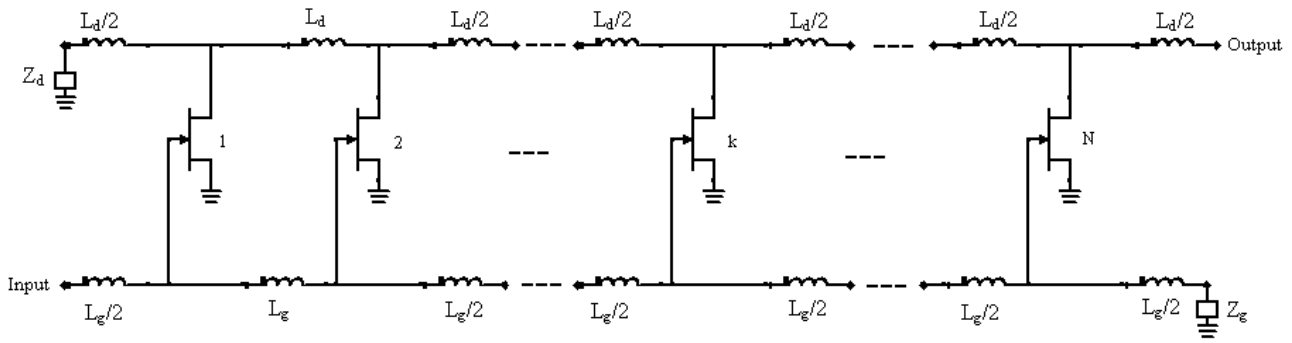


Figure 1. A distributed amplifier circuit diagram.

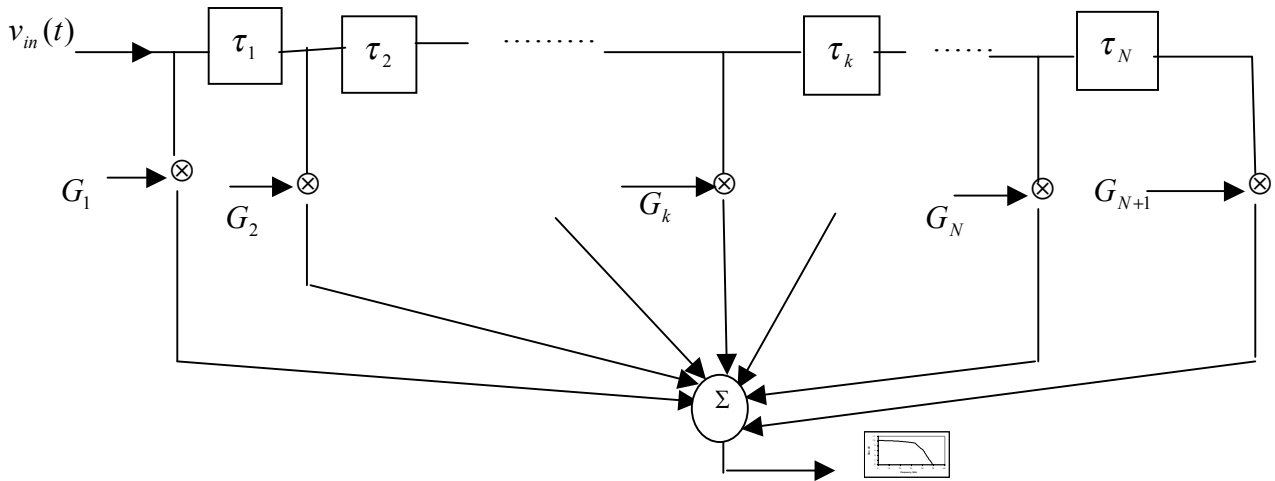


Figure 2. A generalized transversal-filter block diagram.

capacitances of the transistor [6]. Figure 1 depicts a schematic diagram of a distributed amplifier. For a transistor with small parasitic capacitance, the cutoff frequencies of artificial transmission lines are very high, so distributed amplifiers constructed with these lines have inherent broadband characteristics. As in this paper, the interest lies in amplifiers with signal shaping characteristic, we introduce the analogy between generalized distributed amplifiers and transversal filters. Figure 2 illustrates a generalized transversal filter block diagram. The filter consists delay lines, which are equivalent to the transmission lines presented by inductors in Figure 1. As can be seen

from Figure 2, the sampled outputs are multiplied by the coefficients G_1, G_2, \dots, G_{N+1} and summed to form the final output. The more general form of a distributed amplifier that is equivalent to Figure 2 can be shown as in Figure 3. In this figure, the input and output transmission lines are modeled as delay lines and coefficients G_1, G_2, \dots, G_{N+1} have been represented by transistor gains. For the Figure 3, the output signal is [5]

$$v_{out}(t) = \sum_{-N}^N G_k v_{in} [t - k(\tau_g - \tau_d) - N(\tau_g + \tau_d)] \quad (1)$$

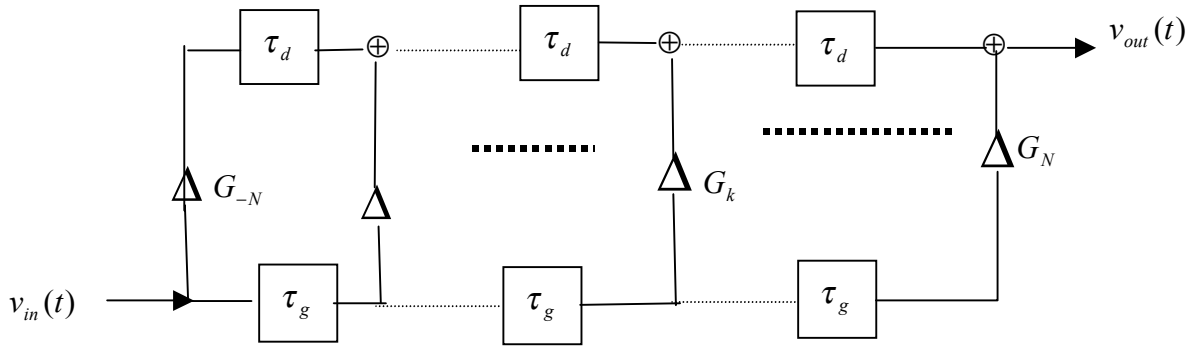


Figure 3. Distributed amplifier with transversal filter topology.

with corresponding signal spectrum

$$V_{out}(f) = \sum_{k=-N}^N G_k V_{in}(f) e^{-j2\pi f k(\tau_g - \tau_d)} e^{-j2\pi f N(\tau_g + \tau_d)} \quad (2)$$

where $V_{out}(f)$ and $V_{in}(f)$ are Fourier transforms of $v_{out}(t)$ and $v_{in}(t)$ respectively. From the above equation, the amplifier transfer function is

$$H(f) = \left[\sum_{k=-N}^N G_k e^{-j2\pi f k(\tau_g - \tau_d)} \right] e^{-j2\pi f N(\tau_g + \tau_d)} \quad (3)$$

This is the same transfer function for Figure 2 with equivalent tap delays of $\tau_k = (\tau_g - \tau_d)$.

The appropriate delay and gain coefficients can be obtained by a Fourier expansion of the raised cosine spectrum in the frequency range of 0-40GHz as will be discussed below.

3. DESIGN EXAMPLE

It is obvious that the term $e^{-j2\pi f N(\tau_g + \tau_d)}$ in Equation 3 has no effect in the amplitude of the $H(f)$ and it only changes the phase and so it is not

important in the calculations of the gains. The terms in the bracket in Equation 3 are the same as those of FIR filter which has been sampled at the rate of $f_s = 1/(\tau_g - \tau_d)$ in the output. As the range of raise cosine is limited to 40 GHz, the sampling frequency should be at least twice of this frequency, so, $f_s = 80 \text{ GHz}$ and $\tau = \tau_g - \tau_d = 1/80 \text{ GHz} = 12.5 \text{ ps}$.

The impulse response of raise cosine is a function valued from $-\infty$ to $+\infty$ (in time domain) so its sampled values (with sampling rate of f_s) should be close to an impulse response of an IIR. For these two functions to be as close as possible, we should minimize the difference between sampled raise cosine in frequency domain and $H(f)$ (minimizing the energy functions difference). For this minimization, we will define an error function as

$$e = \sum_{k=-\infty}^{\infty} |h_r(k\tau) - h(k\tau)|^2 \quad (4)$$

where $h(t)$ is our function and $h_r(t)$ is impulse response of FIR (sampled raise cosine) filter. If in Figure 3 we take $N = 2$ (5 stage amplifier), then $h(k\tau)$ has only five terms from $k = -2$ to $k = 2$. So error function is minimized when these five values of the $h(k\tau)$ are equal to five values of $h_r(k\tau)$ in

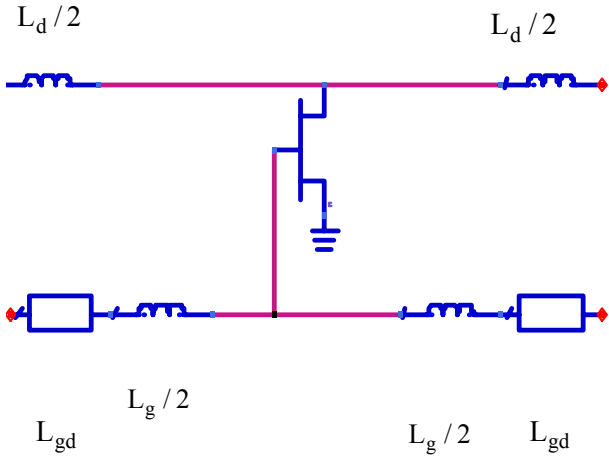


Figure 4. Single section of distributed amplifier with added delay line, L_{gd} , in gate transmission line.

their order. For raise cosine we have

$$h_r(t) = \frac{\cos 2\pi\beta t \sin(\pi\tau_b t)}{1 - 4\beta^2 t^2 \pi\tau_b t} \quad (5)$$

and $h(t)$ is inverse Fourier transform of Equation 3 which is

$$h(t) = \sum_{k=-2}^2 G_k \delta(t - k\tau - N(\tau_g + \tau_d)) \quad (6)$$

where $\tau_b + \beta = 40$ GHz and $\tau = 12.5$ ps. From Equations 4, 5 and 6, it is obvious that, $h_r(k\tau) = G_k$, so gain of k th stage amplifier is

$$G_k = \frac{\cos 2\pi\beta k\tau \sin(\pi\tau_b k\tau)}{1 - 4\beta^2 k^2 \tau^2 \pi\tau_b k\tau} \quad (7)$$

Substituting k from -2 to 2 and $\tau = 12.5$ ps into Equation 7, we can calculate G_{-2} to G_2 as follows:

$$G_{-2} = G_2 = 0.16 \quad G_{-1} = G_1 = 0.71 \quad G_0 = 1$$

It should be noted that the above values are normalized values of each active device gain, so to design an amplifier with gain of A , all the above gain values should be multiplied by A . This renormalization is based on the following equation

$$\frac{g_{mk}}{\max(g_{mk})} = \frac{G_k}{\max(G_k)} \quad (8)$$

where $\max(G_k) = G_0 = 1$ and g_{mk} is k th stage transconductance of the amplifier.

For a HEMT transistor the gate-source capacitance, C_{gs} , is much higher than its drain-source capacitance, C_{ds} , so, for a given impedance

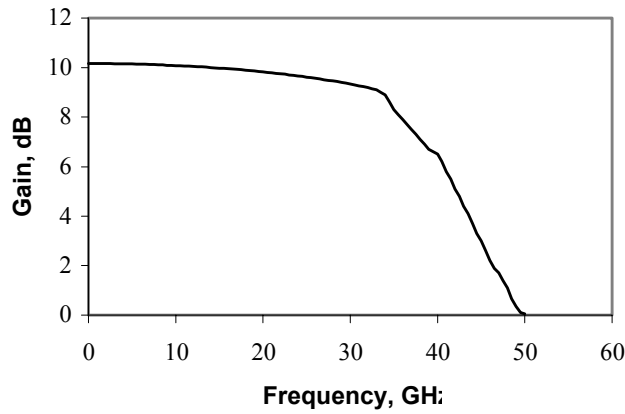
(given $\sqrt{\frac{L}{C}}$), the delay inherent in the gate artificial transmission line (which is equal to $\sqrt{L_g C_{gs}}$) is higher than that of drain line (both

C_{gs} and L_g are higher than C_{ds} and L_d since the characteristic impedances of gate and drain line are equal). To realize this delay difference, which in our case is $\tau = \tau_g - \tau_d = 12.5$ ps, we should place a

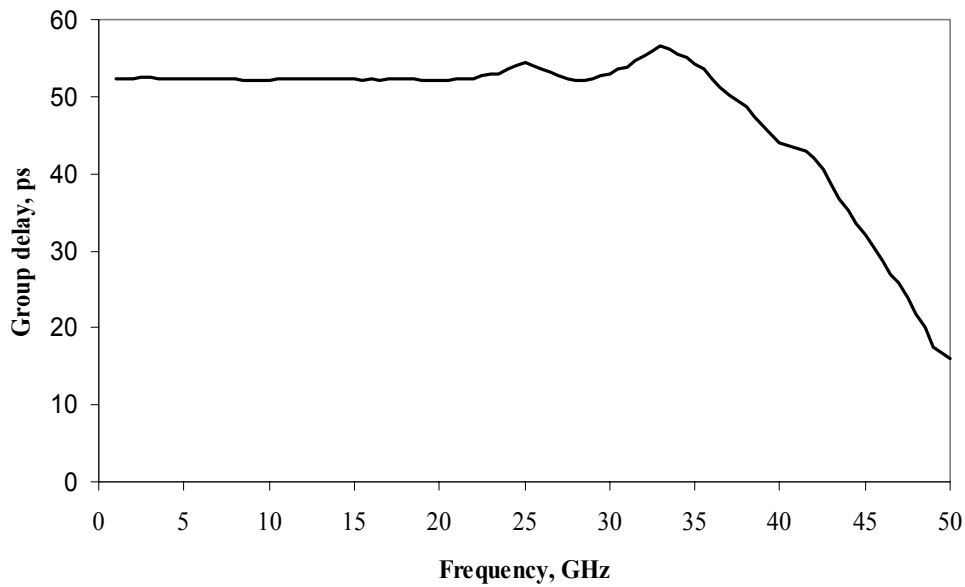
delay lines in series with gate inductors. This has the advantage of reducing the circuit size. Figure 4 depicts a single section of distributed amplifier in which delay lines placed in series with gate line. The size of each transistor is selected proportional to the gain values G 's. The delay element shown in Figure 4 as line L_{gd} , is designed to have an effective delay ΔT given by

$$\Delta T = 0.5 [\tau - (T_g - T_d)] \quad (9)$$

where $\tau = 12.5$ ps and $T_g = \sqrt{L_g C_{gs}}$ and $T_d = \sqrt{L_d C_{ds}}$ are gate line and drain line delays respectively. As an example, for a typical MESFET having $C_{gs} = 0.27$ pF and $C_{ds} = 0.11$ pF and transmission line characteristic impedance of 50^Ω , $L_g = 0.675$ nH and $L_d = 0.275$ nH (note that



(a)



(b)

Figure 5. (a) Gain characteristic of designed distributed amplifier; (b) Group delay characteristic of designed distributed amplifier.

$$Z_0 = \sqrt{\frac{L_g}{C_{gs}}} = \sqrt{\frac{L_d}{C_{ds}}} = 50\Omega$$

For this transistor, we have $T_g = 13.5$ ps and $T_d = 5.5$ ps, then, from Equation 9 the delay element should provide a delay of 4ps to maintain the delay difference of $\tau = 12.5$ ps between gate and drain lines.

4. RESULTS

From the above design procedure, a five stage distributed amplifier was designed.

Figure 5 shows the simulated delay and gain characteristics of the designed amplifier using ADS (Advanced Design System) software and HEMT model introduced in the software

library. It is clear from this figure that desired delay characteristic is obtained to the highest frequencies of interest.

5. CONCLUSION

A novel method for designing a self-equalized distributed amplifier has been presented and discussed. The method is based on analogy between transversal filter and distributed amplifier topologies. From the described method, we obtained gain of each transistor and delay lines element to be added to each gate transmission line to achieve the required response. Simulated results show the practicability of the proposed technique and its application in optical transceivers where pulse shaping is required to minimize the intersymbol interference.

6. REFERENCES

1. Darwazeh, I., Lane, P. M., Marnane, W. P., Moreira, P., Watkins, L. R., Capstick, M. H. and O'Reilly, J. J., "GaAs MMIC Optical Receiver with Embedded Signal Processing", *Proc. Inst. Elect. Eng.*, Vol. 139, Pt. G, No. 2, (April 1992), 241-243.
2. Jutzi, W., "Microwave Bandwidth Active Transversal Filter Concept with MESFET's", *IEEE Trans. Microwave Theory Tech.*, Vol. MTT-19, (September 1971), 760-767.
3. Matsuda, S., Kobayashi, K. and Kira, H., "A 100 GHz Distributed Amplifier in Chip-Size Package", *IEEE MTT-S Digest*, (April 2003), 1029-1032.
4. Lee, G., Ko, H. and De Falavii, F., "Advanced Design of Broadband Distributed Amplifier Using SiGe BiCMOS Technology", *IEEE Radio Frequency Integrated Symposium*, (June 2003), 703-706.
5. Moreira, P., Darwazeh, I. and O'Reilly, J. J., "Distributed Amplifier Signal Shaping Strategy for Multigigabit Digital Optical Transmission", *Electron Lett.*, Vol. 29, No. 8, (April 1993), 655-657.
6. Beyer, J., Prasad, S., Becker, R., Nordman, J. and Hohenwarter, G., "MESFET Distributed Amplifier Design Guidelines", *IEEE Trans. Microwave Theory Tech.*, Vol. MTT-32, (June 1984), 268-275.