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MMIC based Wideband Amplifier for Receiver Back-End Circuitry with Distinct Semiconductor Technologies – A Survey

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Abstract: The wideband amplifier is much in trend now a days, as in the era of miniaturization less circuitry is required to get the more outcome, using the optimum area and weight. So the miniaturization is possible in the semiconductor technology with less area consumed by the lumped components and the active devices. One of the renowned technique is MMIC (Microwave Monolithic Integrated Circuit) significantly used for the RF and Microwave Circuits design. So in this paper, it is discussed about the different design methodology of wideband amplifier using MMIC and its evolution with other semiconductor technologies. The paper also contains the important results and its comparison with recent trending technologies. Wideband amplifier are used in the remote sensing area, wireless communication, space communication to amplify and boost small signal for the large frequency band with better stability and no oscillations. The proposed paper is the survey of various MMIC based techniques using different semiconductor technology and its outcome comparison.
Keywords: Wideband amplifier, Broadband amplifier, MMIC based amplifier, Low noise amplifiers, front-end receiver amplifier.

I. INTRODUCTION

Advancement in the semiconductor technology tends to change is materials used to manufacture the devices. Hence, it is much more important to choose the material which gives the efficient outcome and used according to the application. Now days, it is a trend of miniaturization of circuit. Within the few years according to the Moore`s law, “the transistor at every 18 months get doubled and size is reduced and computing power is increased.” But this law will be legible up to few years or it must have an end. So what after that, hence the researchers are behind this to get the law to be true for the infinite period. So up gradation is needed to overcome the trade-offs by inventing the new technologies. The different design techniques have its own pros and cons depending on their application. The year 1985 was known as the era of “band gap engineering” in which the technique of mixing different semiconductors materials to make the hetero junction device for solid state properties [8]. So hence the MMIC i.e. Monolithic Microwave Integrated circuits came in to existence

Material	Electron Mobility (cm^2/Vs)	Peak Velocity ($\times 10^7$ cm/s)	Frequency Range (GHz)	Noise Figure	Gain	Comments
Si	900–1,100	0.3–0.7	< 20	Moder-ate	Moderate	Mature process; 12-in. wafers
SiGe	2,000–300,000	0.1–1.0	10–40	Lower	Better	Benefits from Si; 6-in. wafers
SiC	500–1,000	0.15–0.2	15–20	Poor	Lower	4-in. wafers
GaAs	5,500–7,000	1.6–2.3	>75	Lower (F_{min} at 26 GHz = 1.1 dB)	Higher (G_{ass} at 26 GHz = 9.0)	Less mature than Si; 3-, 4- and 6-in. wafers
GaN	400–1,600	1.2–2.0	20–30	Poor	Lower	Less mature than GaAs; V_{br} > 100V; 2-in. wafers
InP	10,000–12,000	2.5–3.5	>115	Lower (F_{min} at 26 GHz = 0.9 dB)	Higher (G_{ass} at 26 GHz = 11.1)	Less mature than GaAs; 2-in. wafers

Fig 1.Comparision of different semiconductor materials [8]

The word "Monolithic" means single stone, which briefs that for the microwave and RF circuits (300 MHz- 300 GHz) frequency range the circuit will be fabricated from a single piece of semiconductor material [8]. This leads to the invention of the HEMT (High Electron Mobility Transistor), HBT (Heterojunction Bipolar Transistor), p-HEMT (pseudomporhic High Electron Mobility Transistor). The comparison of the various semiconductor materials parameter is shown in the figure 1. The Si i.e. Silicon is the most basic material used as semiconductor material in active devices due to its availability. GaAs and GaN are the materials used for the high free component due to its properties at high frequencies.

For the RF and Microwave circuits design there are basically three types of design methodologies: A.) Discrete circuit design. B.) Hybrid MIC, C.) MMIC. So as the frequency increases the component size becomes smaller hence at the higher frequencies the MMIC are more preferable to get the desired outcomes.

The Hybrid MIC is less costly but heavier and bulky compared to MMIC. The hybrid MIC is mounted on the alumina or duroide substrate that is designed in few cm^2 areas. The components can be replaced and large varieties of components are available. But in space application it is more subject to save area. So MMIC have very less space and they are very less bulky and light in weight. Up to thousands of devices can be fabricated on a single chip. But it is necessary for MMIC to select and use a proper foundry otherwise there very large loss of money and time as MMIC are much more expensive than the other circuit design methodologies. So in this paper we are going to focus mainly on the device that will be used for the MMIC based broadband amplifier designing. As described previously in paper that as the frequency increases there will be decrease in the size of the circuit, so the problem arise which device to choose for what frequency range. So basically amplifiers are having some specifications, according to the foundries are need to be chosen. The significant specifications prior the amplifier design are the band, gain, bandwidth, return loss, VSWR, noise factor, cascaded gain, etc.

A. Choice of the Device

As it is specified in pervious discussion that MMIC is made or fabricated from a single type of semiconductor so it is desired to choose that which device will match according to the required specification. So starting with the MOSFET (Metal oxide Field Effect Transistor) are mainly made of Si (silicon) or Germanium (Ge). So the gain is achieved up to some range of frequency, for high speed, we can increase μ_n and reduce gate length so that the current can be increased. This gate length can be reduced up to some μm then scaling of device is not possible and MOSFET provides the gain up to some range of frequency.

The degradation in channel width up to some range, we can use instead it the FinFET technology, which has varied gate length up to 20nm. Further the material is been changed to increase the output current so using instead of Ge or Si material , GaAs (Gallium Arsenide) with higher mobility approximately 5 times more than that of silicon. The band gap is also higher hence nearer to the insulating material but called semi insulating substrate. It also provides higher temperature operation. So GaAs based MOSFET were used for the specific applications to get the higher current gain compared to Si/Ge substrate MOSFET.

As the GaAs is a semi insulating substrate it also has some limitations such as no native oxide and have high interference stage. To solve this issue the GaAs was used for the MESFET (Metal field effect transistors) where oxide layer was not present. In MESFET schottky metal semi junction is used as gate so it is always an ON device. The use of schottky metal barrier gate is to control the flow of current and conducts positive voltages. It works also as a switch when applied negative voltages by increasing and decreasing depletion width. The limitation of it was noisy and even cannot be used for higher frequencies due to large variation in current. The devices discussed are mainly used for the low frequency band amplification and they also don't provide much broader band amplifier. Hence to further develop the semiconductor technology it is desired lay- over on the hetero-junction devices. The physical separation of electrons and ionized donor is preferred, achieved using different band gap materials. The hetero-junction provides different band gap hence 2D electron gas structure is formed due to high accumulation of electrons. This 2D electron gas structure is used in HEMT (High Electron Mobility transistors) and HBT (Heterojunction Bipolar Transistors).

The HEMT are the device which provides higher gain, higher linearity and lower noise at higher frequency. HEMTs are made of AlGaAs / GaAs substrate that gives the stable current as electrons are majority charge carriers no minority carriers are involved and broadband property is also achieves with the lesser biasing. p-HEMT are pseudomorphic HEMT which provides more better linearity than HEMT. They are the combination of InGaAS / AlGaAs/ InP . Mainly for the MMIC based applications p-HEMT are more preferable. The figure 2. Shows the different circuit use different devices.

As mentioned in the figure 2 the MMIC based power amplifier, broadband amplifier, low noise amplifier are mainly designed using the HEMT, HBT or p-HEMT. So according to the application and its requirement of frequency band the active semiconductor is been chosen. HBT are used for the high power high frequency application hence now basically and significantly for low noise, high gain at higher frequency two choices is left i.e. HEMT and p-HEMT.

	Bipolar	FET			
	CMOS	SiGe HBT	GaAs/ InP HBT	MESFET	HEMT
Oscillator	—	✓	✓	—	—
Mixer	—	✓	✓	—	—
Low-noise amplifier	—	✓	✓	—	✓
Power amplifier	—	—	✓	—	✓
Switch	—	—	—	✓	✓
Digital	✓	✓	—	—	—

Fig 2. Different technologies for various circuit design.[8]

The basic block diagram of amplifier is shown below which consists of the amplifier device which is nothing but the p-HEMT or HEMT active device, input/output matching network to match the 50 ohms of impedance with the circuit's impedance. Feedback network is designed to provide the wide band .The DC bias circuit is the supply voltages that is been calculated as fixed DC bias point in form of current and voltages.

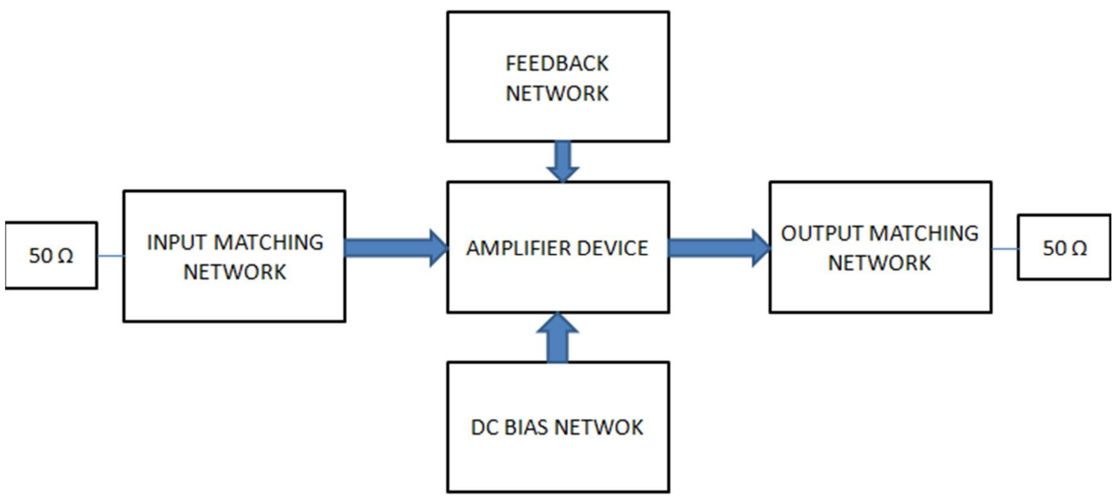


Fig 3. Basic simplified block diagram of wideband amplifier using feedback technique

II. LITERATURE REVIEW

As discussed earlier CMOS cannot be used for the high frequency amplifier as the gain cannot be achieved as its maximum frequency is up to MHz or some GHz range as capacitance behaves short circuit at higher frequency. So as discussed for MMIC based amplifier it is more preferable to use the HEMT or p-HEMT so here is the comparison of different broadband amplifier design using the design process and devices. Basically p-HEMT is considered as the highly linear, high gain, low noise device so used for broadband amplifier design [1] [3] [4] [5] [7].

Here is the comparison of various types of broadband amplifier design as shown in table 1. The table consists of the comparison of the frequency band, gain, gain flatness, and mainly about the design process as each design process has its own maximum frequency range and other limitations. The design process used for MMIC are mainly the p-HEMT, HEMT, GaN HEMT process ,as these of the active device provides larger gain, higher linearity, lower noise for higher frequencies. So the table justifies various techniques comparison

Table I
Comparison of various types of broadband amplifier design

References	Frequency Band (GHz)	Design Process	Gain (dB)	Gain Flatness (dB)	Bandwidth (GHz)	Return loss (dB)	Year
[1]	6-18	0.15 µm p-HEMT	17.4	± 1 dB	12	≤ -10	2019
[2]	0.5-1.5	GaN HEMT	13.8	± 1 dB	1	≤ -10	2017
[3]	9.6	0.25 µm pp-HEMT (PPH25X)	20	± 1 dB	0.6	≤ -16	2017
[4]	17-35	0.15 µm GaAs p-HEMT	10	± 2 dB	17	≤ -10	2012
[5]	2.4-2.5	0.15 µm p-HEMT	30	± 1 dB	0.1	≤ -8	2007
[6]	2.7-3.5	GaN power transistor	10	± 1 dB	0.8	≤ -10	2009
[7]	0.4-0.8	GaAs p-HEMt	42	± 1 dB	0.4	≤ -10	2018
[9]	4.5-52	GaN device	11.6	± 1 dB	0.7	≤ -20	2019

H. lee et al.[1] The GaAs p-HEMT based broadband amplifier with dual frequency selective impedance matching technique is designed for the range of 6-18 GHz [1], it has very high bandwidth. The gain is achieved using the impedance matching with the upper and lower frequency corners and feedback is provided for wideband. The PAE achieved is 13 to 21.7% with 1.19x0.82 mm^2 chip size.

W.M. Malik et al. [2] The other paper with the band 0.5-1.5 GHz is designed based on wideband load pull and source pull analysis [2]. The amplifier provides more efficiency i.e. 40-68% but the gain is low compared to other. This amplifier is designed using GaN power transistor appropriate for implementation in various wireless communication systems. The achived is 13.8 dB with ±1 dB gain flatness over the entire band[2].

T.Paul et al.[3] The amplifier can also be designed for the particular frequency so here is one of them 9.6 GHz X-band amplifier design using pp-HEMT process using self bias resistor technique basically designed for the satellite payload application [3].

J. Nilsson et al.[6] The S-band MMIC based amplifier is designed for the output stage of phased array radar system or as a driver for higher power fixed antenna system. The two stage is designed using GaN HEMT and has the PAE of 55% and is designed within the 12.5 x 12.5 mm chip size. The excellence thermal properties of GaN –on- SiC allow the device to maintain its performance over a wide variety of pulse widths and duty cycles [6].

T.Kulatunga et al.[7] The GaAs p-HEMT based 0.4 – 0.8 GHz amplifier is designed using the folded cascode technology with capacitor in feedback to achieve lower noise for LNA. This two stage amplifier is been used for the aperture synthesis radio telescope [7]. The outcome of the amplifier is from 41.1 – 13.3 dB gain (S_{21}) , further the noise figure is very low i.e. 0.26 – 0.34 dB over the entire band. The temperature also exhibits in the range of 18.8-26.3 K which are the required specification.

G. Lv et al.[9] The proposed design is of a GaN HEMT based Doherty amplifier for the c-band. The Doherty power amplifier (DPA) is the most popular architecture for average efficiency enhancement due to its high back-off efficiency[9]. The design was implemented using WIN semiconductor and implemented using Momentum in ADS software. The gain achieved was 11.6 dB and return loss better than 20 dB for the required band[9].

III. CONCLUSION

From the above survey it is been noted that various amplifier design of wideband amplifier has its own pros and cons according to the application required. The trade-off between the gain and bandwidth is seen but it can be solved using the wideband active devices. The cost is comparatively high of MMIC circuits compared to other semiconductor technologies, but at the advantage of high gain, wider bandwidth the cost is negligible. This type of technologies is mainly used for the wireless communication, space communication.

The detailed study and comparison is been evaluated using different techniques as shown in the comparison table of performance specification Table 1. The comparison shown in the table justifies the differences in bands and their gain with the bandwidth flatness. Moreover the table signifies the various types of amplifier design using MMIC as there is much need of miniaturization in today`s era.

REFERENCES

[1] H. Lee, W. LeeT. Kim, M.Helaoui, F.M. Ghannouchi Y.Yang., "6_18 GHz GaAs pHEMT Broadband Power Amplifier Based on Dual-Frequency Selective Impedence Matching Technique, Access IEEE, vol. 7, pp. 66275 - 66280, 2019.

[2] W.M. Malik, A.A.Sheta,I.Elashafiey, "Development of Efficient High Power Amplifier With More Than an Octave Bandwidth", IEEE ACCESS Vol . 6. 2169-3536, 2018

[3] T. Paul, M. Harinath, S.K. Garg, "X-Band Self Biased MMIC Amplifier using 250nm GaAs pHEMT" process",IEEE TT-S International Conference Microwave and Rf Conference (IMaRC) 2377-9152,2017

[4] P.C. Huang, Z.M. Tsai, K.Y. Lin, H Wang, "A 17–35 GHz Broadband, High Efficiency PHEMT Power Amplifier Using Synthesized Transformer Matching Technique",IEEE Transaction on Microwave Theory and Technique,vol 60, 1557-9670, 2012

[5] C-K Chu, H-K Huang, C-CWang, Y-H Wang et al. "A 3.3V self-biased 2.4-2.5 GHz high Linearity PHEMT MMIC power amplifier," ESSCIRC 2004- 29TH European solid State Circuits conference, 0-7803-7995-0, 2003

[6] J. Nilsson, N. Billstrom, N. Rorsman, P. Romanim, "S-band Discrete and MMIC GaN Power Amplifiers", 4th European Microwave International Circuits Conference, 978-1-4244-4749-7, 2009.

[7] T. Kulatunga, L. Belostotski, J.W. Haslett ,"400-to-800-MHz GaAs pHEMT-Based Wideband LNA for Radio-Astronomy Antenna-Array Feed", IEEEMicrowave and Wireless Components Letters , Vol 28 Issue 10, 2018

[8] Practical MMIC Design by Steve Marsh, 2006

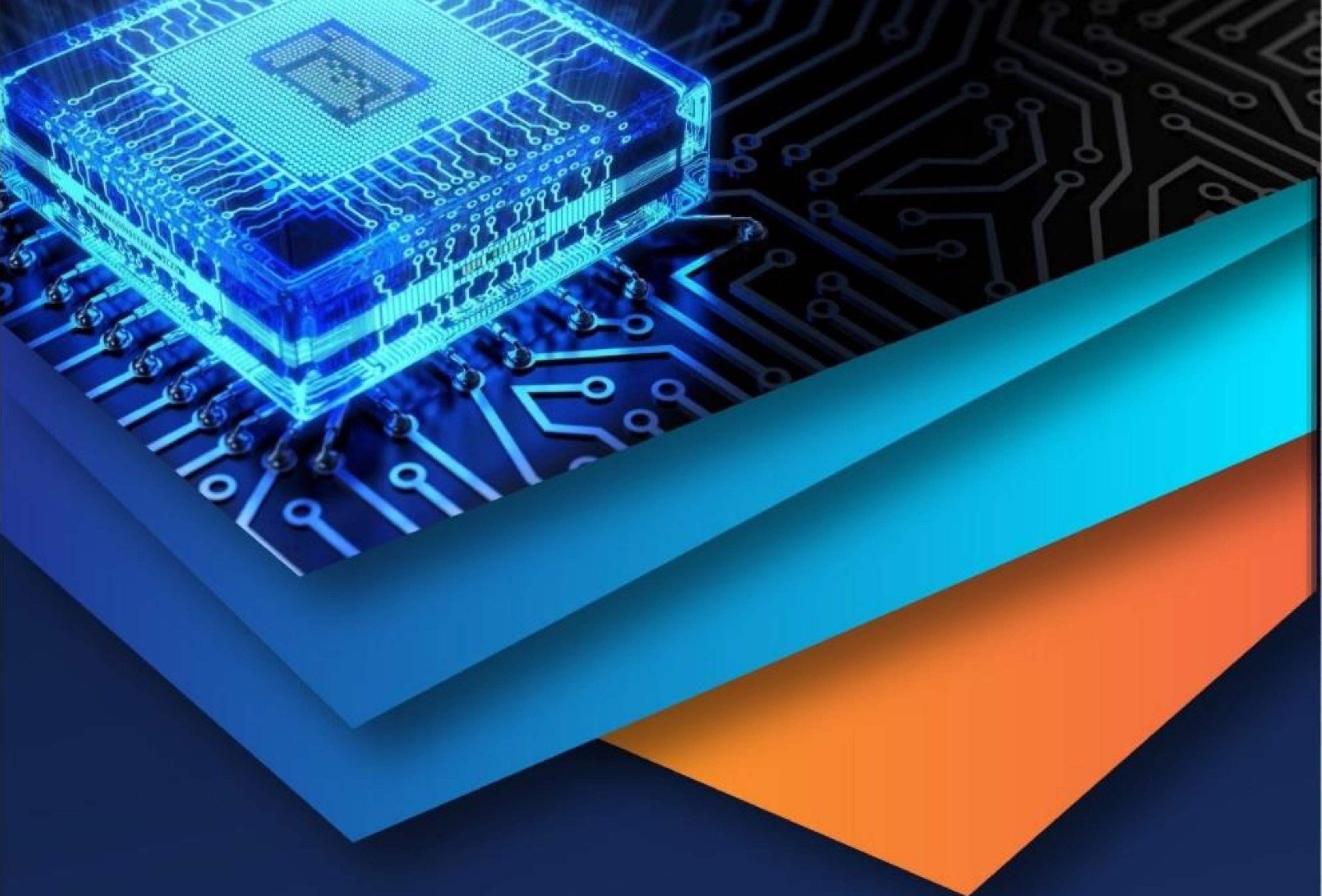
[9] G. Lv, W. Chen, L. Chen and Z. Feng, "A Fully Integrated C-band GaN MMIC Doherty Power Amplifier with High Gain and High Efficiency for 5G Application," 2019 IEEE MTT-S International Microwave Symposium (IMS), Boston, MA, USA, 2019, pp. 560-563.

[10] W. Lee et al., ``X-band two-stage Doherty power amplifier based on prematched GaN-HEMTs," IET Microw. Antennas Propag., vol. 12, no. 2,pp. 179_184, Feb. 2018.

[11] Sajedin, M.; Elfergani, I.; Rodriguez, J.; Abd-Alhameed, R.; Barciela, M.F. A Survey on RF and Microwave Doherty Power Amplifier for Mobile Handset Applications. Electronics 2019, 8, 717.

[12] E. Camargo, J. Schellenberg, L. Bui, and N. Estella,"Power GaAs MMICs for E-band communications applications," in IEEE MTT-S Int. Dig., Jun. 2014, pp. 1–4

[13] Y. Park et al., ``GaN HEMT MMIC Doherty power amplifier with high gain and high PAE," IEEE Microw. Wireless Compon. Lett., vol. 25, no. 3, pp. 187_189, Mar. 2015.



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