

750MHz Power Doubler and Push-Pull CATV Hybrid Modules Using Gallium Arsenide

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Abstract

For the growing channel capacity in the CATV market, a new breed of Push-Pull (Pre Amp) and Power Doubler (Post Amp) amplifiers have been developed that operate to 750MHz. These units incorporate highly reliable GaAs MMICs, surface mount transformers and advanced manufacturing technologies which have resulted in significant improvements in amplifier performance.

INTRODUCTION

In order to accommodate the increasing worldwide demand for broadband services over the television medium, CATV operators are increasing the amount of channels that are being transmitted to their customers. Distribution amplifiers are required to operate to 750MHz, 860MHz and even to 1GHz. To address this increasing demand for greater bandwidth in the hybrid amplifiers, GaAs technology has been selected for its excellent frequency and noise performance. This paper describes newly developed hybrid amplifiers that use GaAs technology for the active devices and all surface mount components in the substrate assembly. The results are high performance and highly repeatable Power Doubler and Push-Pull amplifiers that operate to 750MHz.

SURFACE MOUNT DESIGN

In large volume production, there is significant pressure to minimize the cost of assembly while providing repeatable performance. The primary method of achieving this goal in this development was to automate the entire assembly process and reduce the component count. This requires that all components be packaged for surface mount attachment to the substrate. Based on the components in the existing, traditional hybrids, this necessitated that the active devices and the transformers be re-designed to be compatible with existing automated assembly equipment.

Transformers

The development of the surface mountable transformer presented a significant technical challenge. Not only did the new device need to be in a surface mount style package, it was not to require any tuning after assembly. Many different approaches were tried: thin film, flexible substrates and alumina substrates to name a few. None of these designs had adequate electrical performance. The final design was an auto-transformer configuration using a double ferrite core. This configuration offered a small size,

6.2mmx6.2mm by 3.9mm high, that can be mounted along with other surface mount components. An outline drawing of the transformer is shown in Figure 1.

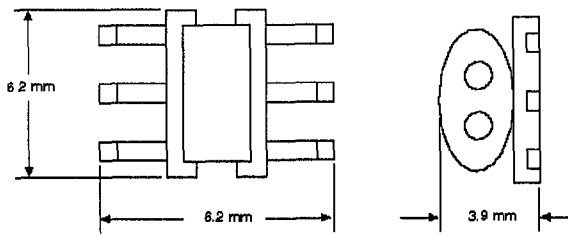


Figure 1. Surface Mount Transformer

Several transformers have been measured in a 50Ω environment for basic characteristics. The insertion loss is less than 2.5dB from 10MHz to 650MHz and is 3dB at 750MHz. The return loss is $>19\text{dB}$ across the band. Also, the worst case phase balance is $\pm 3^\circ$ for the input transformer and $\pm 6^\circ$ for the output transformer.

GaAs MMIC

The other major design effort focused on making the active devices compatible with surface mounting equipment. This involved the design of both a GaAs MMIC and a carrier for the new IC. The most critical issues for this package were heat dissipation, auto insertion and low cost. A plastic package was not feasible due to the heat dissipation of the IC and a ceramic type package was too expensive. A simple leadframe with potting material placed over the active device was the optimum solution. A similar package is used in the manufacture of cellular phone hybrid amplifiers. The leadframe has 22 pins and is made of a nickel-iron, Ni-Fe, alloy with a copper heatsink that attaches directly to the main heatsink of the amplifier. The carrier is shown in cross-section in Figure 2.



Figure 2. Carrier for GaAs MMIC

Historically, multiple transistors have been individually attached and then wire bonded to the substrate. These new amplifier hybrids only have one active device each which incorporate all the transistors. The MMIC is fabricated using a standard NEC GaAs process with a gate length of $1\mu\text{m}$, breakdown voltage (BV_{gd}) of 18V and a maximum current density of $310\text{mA}/\text{mm}$. The CATV MMIC incorporates 6 devices in a push-pull configuration along with biasing resistors. Two of these resistors are used to set the bias of the output stages and dissipate large amounts of DC power. It is advantageous to be able to include these resistors on the MMIC, as it eliminates the need for having high power resistors on the substrate which are large and expensive. The driver stages also have source resistors on the GaAs MMIC. In addition, there are some resistor dividers to set the bias on the gates of the MESFETs (not shown). A simplified schematic for the MMIC is shown in Figure 3.

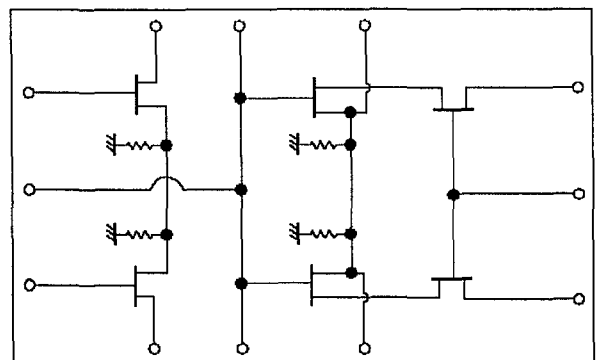


Figure 3. Schematic of CATV MMIC

Assembly

With these changes to the transformers and the active device, the substrate assembly has been fully automated. In fact, these CATV amplifiers are made on the same assembly lines as power amplifiers used in cellular phones. A photograph of a typical amplifier is shown in Figure 4.

The MMIC can be seen in the middle of the substrate, with a transformer at each end. The remaining components are used to provide feedback and biasing for the FETs. The developments detailed thus far have been applied to both the Power Doubler and the Push-Pull amplifiers. In fact, the photograph shown in Figure 4 could easily be of either the Push-Pull or the Power Doubler amplifier because the primary difference is only in the GaAs IC used.

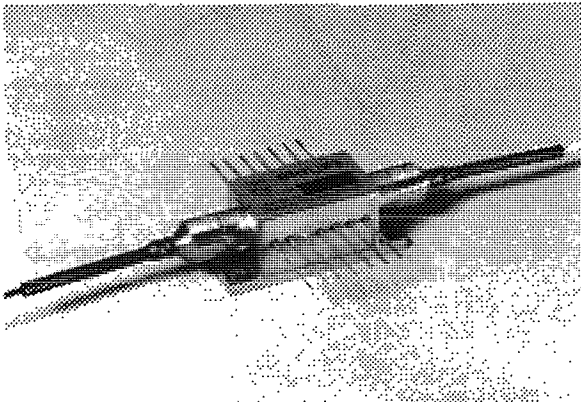


Figure 4. Photograph of substrate

ELECTRICAL PERFORMANCE

With many companies in the process of upgrading the CATV systems to 750MHz, due to the increasing demand for services and competition from DBS, it seemed logical to utilize a technology that is well suited for higher frequency operation. GaAs offers some basic advantages to silicon devices. Primarily, the higher electron mobility of the GaAs devices allows for better frequency

performance, especially for noise figure and gain. While the bandwidth of a Si bipolar transistors is being stretched to cover the 750MHz band, the upper frequency range of a GaAs MMIC is limited primarily by the characteristics of the transformers. With the expected expansion of the bandwidth to 860MHz and even to 1000MHz, GaAs seems to be the logical step to service the anticipated capabilities for the next generation of plant expansion. Each of the major electrical parameters are described in the following section.

Gain

One advantage of using a GaAs device is that there is plenty of gain available at 750MHz. The power doubler and the push-pull amplifier have high typical gain levels of about 22dB. The characteristic shape of the gain curve is the same for both units. A plot of the gain response for the Power Doubler amplifier is shown in Figure 5.

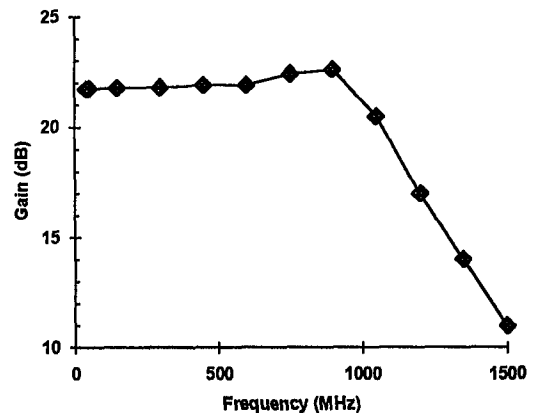


Figure 5. Gain of Power Doubler Amplifier

Noise Figure

Another benefit of the GaAs devices is the low noise figure that is achievable over a broad bandwidth. A characteristic of the Si CATV hybrid amplifiers is that the noise figure increases with frequency. This is due

to the fact that the minimum noise figure for a Si bipolar transistor is quadratically related to frequency. The minimum noise figure for a GaAs MESFET is linearly related to frequency. Consequently, it is not surprising to find that the GaAs device has superior noise performance at the higher frequencies[1]. Both the Push-Pull and Power Doubler amplifiers have maximum noise figures of 5dB over the 50-750MHz frequency range. A plot of this data is shown in Figure 6.

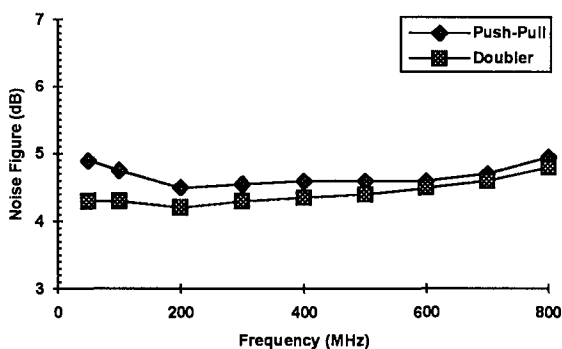


Figure 6. Noise Figure of Push-Pull and Power Doubler Amplifiers

Return Loss

Due to the multiple cascades in amplification along any given cable line, low return loss is critical to minimize reflected power. The transformers contribute significantly to the return loss, with smaller contributions coming from the component values and the input impedance of the active devices. The input and output return losses for the Push-Pull and Power Doubler amplifiers are shown in Figures 7 and 8 respectively. This is an intermediate point in the transformer design. Further development is in process to improve the return loss performance to be a minimum of -18dB across the entire band.

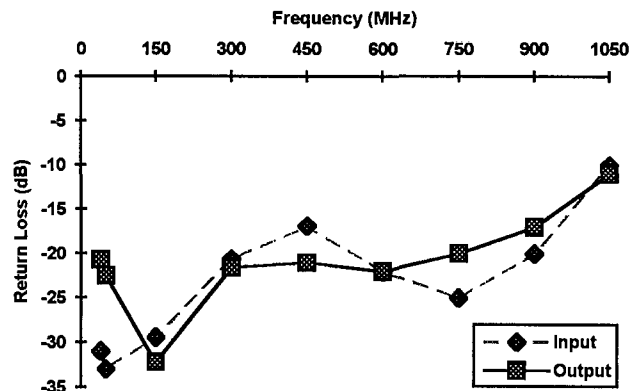


Figure 7. Return Loss of Push-Pull Amplifier

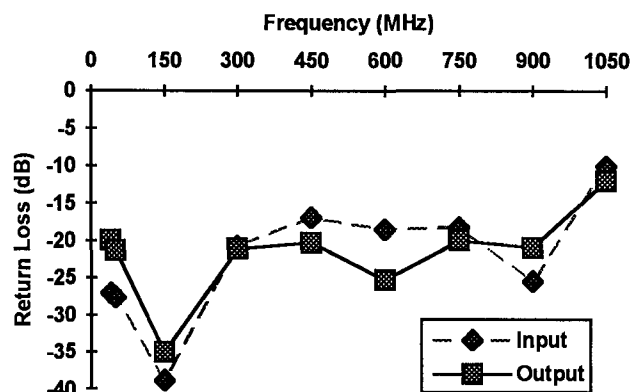


Figure 8. Return Loss of Power Doubler Amplifier

Distortion

This last section of the electrical performance is perhaps the most critical, distortion. It is the primary specification upon which the system performance is judged. The distortion performance of both the Power Doubler and the Push-Pull are extremely good over the entire band. A summary of measured CTB, CSO and XMOD are shown in Table 1.

In particular, the CSO performance stands out as being exceptional. Conventionally, the primary method of canceling second order

products is to use a push-pull circuit topology. This design is no different. However, since all the active devices are included on a single IC, not only are the phase and amplitude characteristics of the

amplifiers very similar and repeatable, but the interconnect parasitics are minimized. This results in a greatly improved cancellation of the second order products generated by the amplifier.

Table 1. Distortion Performance of Push-Pull and Power Doubler Amplifiers

Parameter	Description	Condition	Push-Pull	Power Doubler	Units
CTB	Composite Triple Beat	$V_o=44\text{dBmV}$ 110 channels	-58.1	-63.4	dB
CSO	Composite 2nd Order	$V_o=44\text{dBmV}$ 110 channels	-65.9	-70.0	dB
XMOD	Cross Modulation	$V_o=44\text{dBmV}$ 110 channels	-61.9	-65.1	dB

[data is at 25°C, 50-750MHz]

Table 2. Electrical Parameters of Push-Pull and Power Doubler Amplifiers

Parameter	Description	Condition	Push-Pull	Power Doubler	Units
SL	Gain Slope		0.6	0.9	dB
FL	Gain Flatness		± 0.15	± 0.1	dB
I_{tot}	Total Current	V _{dd} =24V	218	344	mA

[data is at 25°C, 50-750MHz]

Power Consumption

There are a few other parameters that are commonly reported to completely characterize amplifiers of this type. These are summarized in the Table 2. Note that there has been an improvement in the power consumption of the Power Doubler unit. Using a novel biasing scheme, the current required is only 344mA typical. This represents approximately a 20% reduction in power consumption of the amplifier over existing units.

PERFORMANCE: GaAs vs Si

Many of the advantages of choosing a GaAs device have been explained previously. To put the reported performance into a familiar context, Tables 3 and 4 compare the performance of the hybrid amplifiers using a GaAs MMIC and hybrid amplifiers using Si bipolar transistors. It should be noted that the specifications reported for the Si devices are known to be conservative. Actual devices could have performance of 3-5dB below the stated value, depending on the vendor.

Regardless, the distortion levels are still improved by using the GaAs MMIC. Of note, for the Power Doubler amplifier, the

distortion of the GaAs device is better while providing higher gain than the Si device.

Table 3. Performance Comparison Between GaAs and Si Power Doubler Amplifiers

Parameter	Description	Condition	GaAs	Si	Units
Ga	Gain	f=50MHz	21.9	20	dB
		f=750MHz	22.7	21	dB
CTB	Composite Triple Beat	V _o =44dBmV 110 channels	-63	-57	dB
CSO	Composite 2nd Order	V _o =44dBmV 110 channels	-70	-56	dB
XMOD	Cross Modulation	V _o =44dBmV 110 channels	-65	-61	dB
NF	Noise Figure	f=50MHz	4.7	5.5	dB
		f=750MHz	4.9	9	dB
I_{tot}	Total Current	V _{dd} =24V	340	415	mA

[data is at 25°C, 50-750MHz unless otherwise noted]

Table 4. Performance Comparison Between GaAs and Si Push-Pull Amplifiers

Parameter	Description	Condition	GaAs	Si	Units
Ga	Gain	f=50MHz	21.7	21.0	dB
		f=750MHz	22.2	21.5	dB
CTB	Composite Triple Beat	V _o =44dBmV 110 channels	-58	-51	dB
CSO	Composite 2nd Order	V _o =44dBmV 110 channels	-66	-50	dB
XMOD	Cross Modulation	V _o =44dBmV 110 channels	-62	-51	dB
NF	Noise Figure	f=50MHz	4.7	6	dB
		f=750MHz	5.0	8	dB
I_{tot}	Total Current	V _{dd} =24V	218	225	mA

[data is at 25°C, 50-750MHz unless otherwise noted]

REPEATABILITY

Along with the demonstrated improvement in the assembly flow and in the electrical performance, the integration of the transistors on one IC and the use of surface

mount transformers are also beneficial in increasing the repeatability in the performance of the amplifiers. Other designs that use discrete transistors and wire wrapped toroidal cores require tuning to compensate for variations in each of the individual

components. An advantage to using a MMIC is the uniformity in performance of individual elements on the IC. Consequently, each of the transistors on the CATV MMIC will have the same electrical characteristics. Also, the transformers are self-contained, pre-screened units that do not have any tuning sections. The result are amplifiers that emerge from the assembly line with similar performance, thereby eliminating the need to tune each unit. Quality performance is ensured by constant lot testing of a percentage of the production units based on the distribution of performance measured. This reduces the overall time needed to test the amplifiers, and it also reduces the number of test stations. Capital equipment for CATV testing is expensive and these savings contribute to the reduction of the overall cost of the amplifier. Using these assembly and testing techniques on the pre-production units has yielded very encouraging results.

CONCLUSION

Two new types of amplifiers have been developed that can be used in CATV systems. The incorporation of GaAs technology for the active devices results in high gain, low noise figure and excellent linearity. Manufacturing technology has also been enhanced by reducing the component count and designing all the components to be surface mountable. A summary of the measured performance of the Push-Pull and the Power Doubler amplifiers is shown below in Table 5.

As of the writing of this paper, the prototype stage has been completed for this development and pre-production evaluation is in process. More work is being done on the MMIC to further improve the distortion levels, especially XMOD and CTB. Also, the transformers are being optimized in order to improve the input and output return losses. More details will be available during the presentation of the paper.

Table 5. Summary of Performance

Parameter	Description	Condition	Push-Pull	Power Doubler	Units
			Typical	Typical	
Ga	Gain	f=50MHz	21.7	21.9	dB
		f=750MHz	22.2	22.7	dB
SL	Gain Slope		0.6	0.9	dB
FL	Gain Flatness		±0.15	±0.1	dB
S11	Input Return Loss	f=50-750MHz	≥16.5	≥16.9	dB
S22	Output Return Loss	f=50-750MHz	≥18.3	≥17.2	dB
CTB	Composite Triple Beat	Vo=44dBmV 110 channels	≤-58.1	≤-63.4	dB
CSO	Composite 2nd Order	Vo=44dBmV 110 channels	≤-65.9	≤-70.0	dB
XMOD	Cross Modulation	Vo=44dBmV 110 channels	≤-61.9	≤-65.1	dB
NF	Noise Figure	f=50-750MHz	4.85	4.81	dB
I _{tot}	Total Current	V _{dd} =24V	218	344	mA

ACKNOWLEDGMENTS

I would like to recognize and thank the managements of CEL and NEC/CSD for their support in the preparation of this paper. Also, thanks to the NEC engineers in Kawasaki and Kansai who contributed their time to assist in the characterization of the amplifiers.

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