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1991年度MMIC研究成果報告

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ATR光電波通信研究所

MMIC研究成果報告(1991年度版)

概要

1991年度のMMIC研究成果状況(LUFET MMIC、多層化MMIC、多層化LUFET MMIC)をプレゼンテーション用にまとめたものである。

まえがき

ATR光電波通信研究所において、超小型移動体通信器の実現に向けた小型･高集積化MMICのための回路構成法が研究され、5年を経過する。当初、掲げた従来構成のMMICに対し30倍の集積度向上の最終目標に対し、線路一体化FET(LUFET)、多層化構造といった新技術を提案適用し、現在各要素回路において3~10倍の集積度向上(小型化)を果たしつつある。ここでは、LUFET、多層化技術を基本概念を紹介しつつ、その最近のMMIC研究成果状況について報告する。

尚、本文の構成は、プレゼンテーション用の図を頁左側に、これに対応する説明を頁右側に配置する。説明文中の表現は口語形式をとっているので、留意されたい。

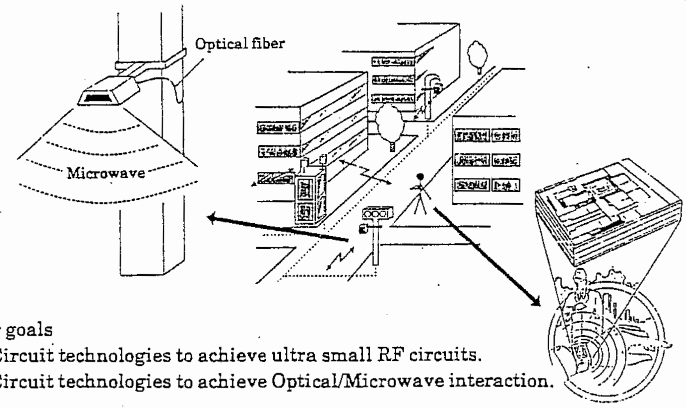
OUTLINE

1. Research Goals of Our Group.
2. Line unified FET MMICs.
3. Multilayer MMICs.
4. MMIC Compatible Optical/Microwave Circuits.
5. Conclusion.

(OHP-1)

This is the outline of today's presentation. First, I will introduce the research objectives of my group. In the 2nd and 3rd section, I'll discuss MMIC circuit technologies for miniaturization, and present some MMICs using such technologies. In the 4th section, I'll present MMIC compatible optical microwave circuits. This will be followed by the conclusion.

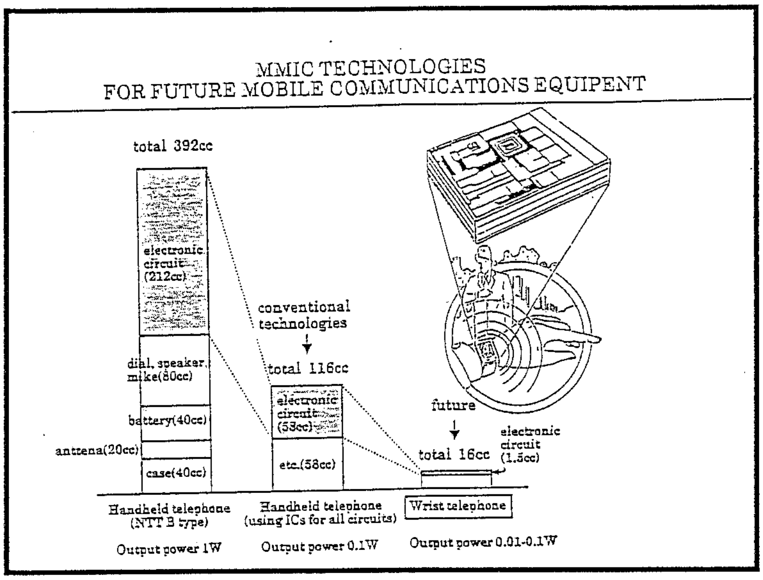
Personal Communication Systems of the Future



Our goals
(1)Circuit technologies to achieve ultra small RF circuits.
(2)Circuit technologies to achieve Optical/Microwave interaction.

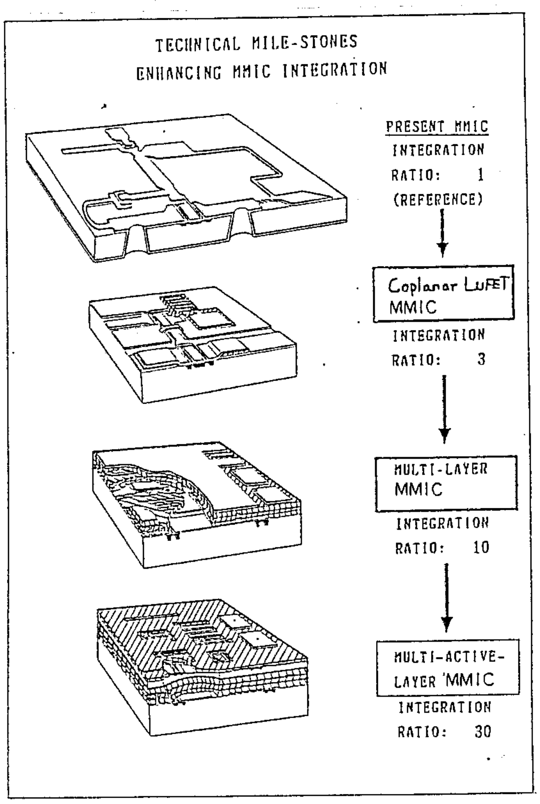
(OHP-2)

This figure shows the personal communication systems of the future. A person will have a compact sized personal terminal such as a wristwatch sized telephone. The terminal will be connected with a radio base station by a microwave or milliwave. One radio base station will cover one town block. The radio base stations will construct a cellular distribution network using optical fiber links. Our objectives are realization of the ultra-small RF circuits, optical/microwave interaction and optical fiber link technologies. In this presentation, I will present MMIC circuit technologies for miniaturization, and optical/microwave circuits which can be fabricated onto MMIC chips.



(OHP-3)

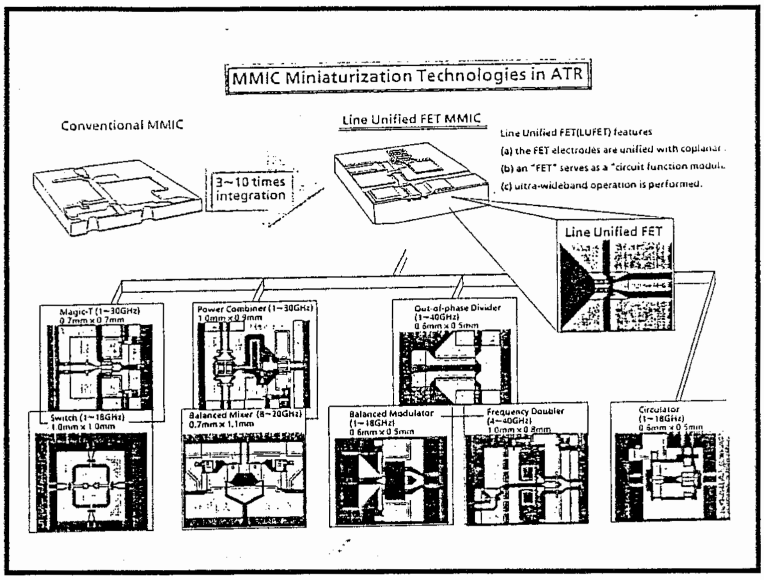
This slide compares the volume of conventional handheld telephones and our goals, the wrist telephone. In comparing the electric circuits, about 30 times greater circuit integration is required.



(OHP-4)

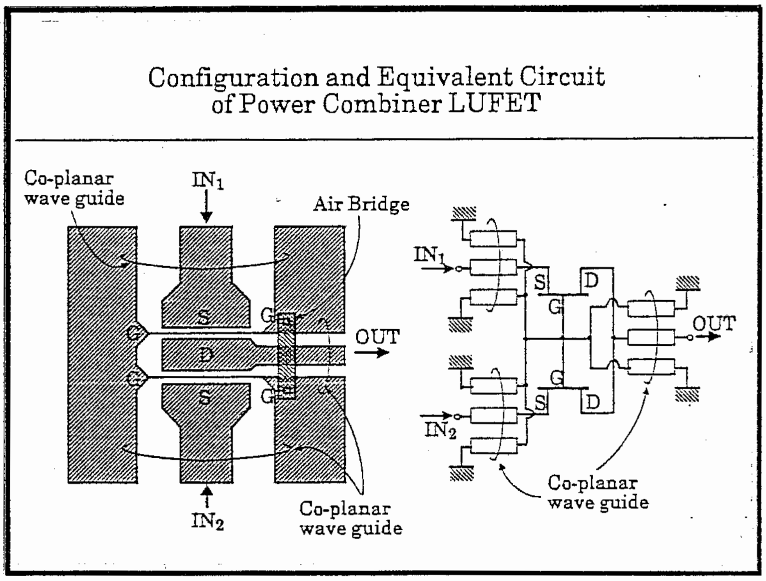
These are the technical milestones to achieve 30 times greater circuit integration. The first step is called the "Coplanar LUFET MMIC", where coplanar lines and Line-Unified FET technologies are used. The second step is called the "Multilayer MMIC", where multilayered microstrip lines are fabricated onto the Coplanar LUFET MMIC. The final step is called the "Multi-active-layer MMIC", where GaAs layers are stacked onto the multilayer MMIC. In the "Multi-active-layer MMIC", both passive devices and active devices such as FETs are stacked onto the GaAs substrate. We are presently at the multilayer MMIC step, so we have achieved three to ten times greater circuit integration compared to conventional MMICs.

(OHP-5)

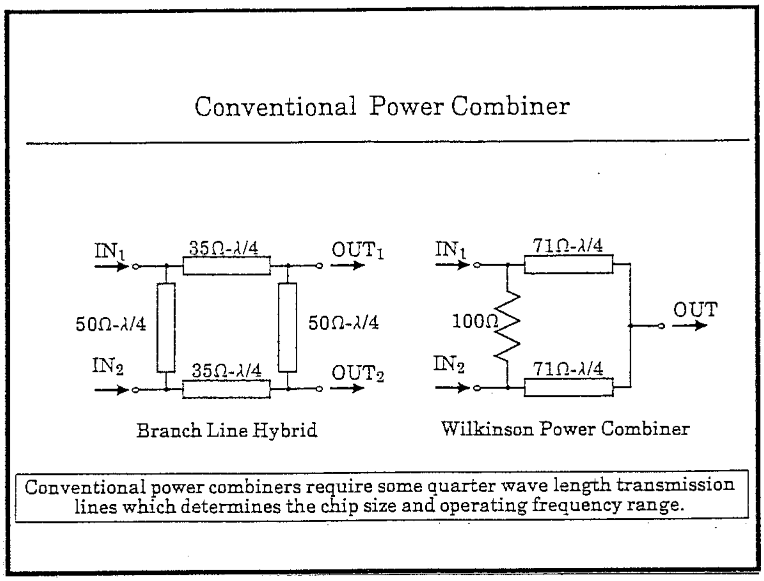


These are the coplanar LUFET MMICs developed at ATR. "LUFET" is the abbreviation for Line Unified FET. In the LUFET, FET electrodes are unified with coplanar lines such as coplanar waveguides and slotlines. By using this LUFET configuration, a circuit function block is achieved in the size of the FET.

(OHP-6)

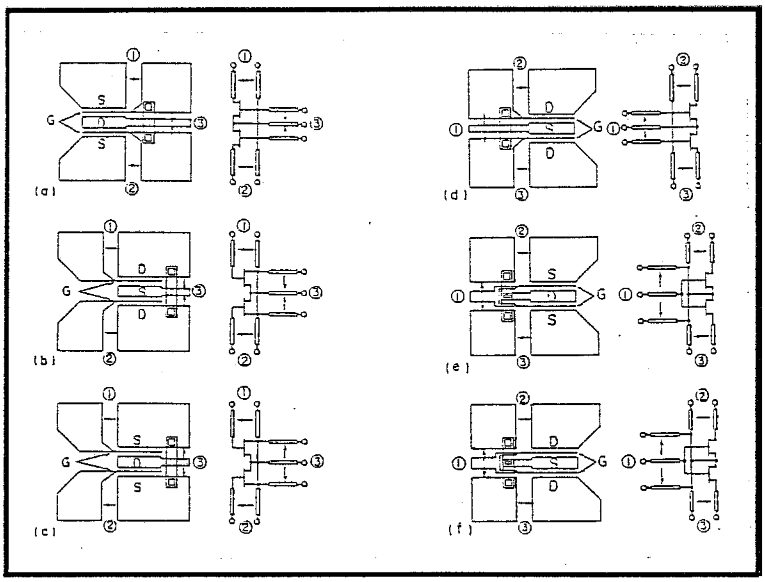


This is a typical example of a LUFET. Co-planar waveguides are constructed in the gate-source-gate electrode structures. Another co-planar waveguide is constructed in the gate-drain-gate electrode structures. This LUFET provides all the functions required from a power combiner in FET configuration only. This LUFET isolates the two input ports, isolates the output from the input ports, combines power, and matches impedance at the input ports. The isolations are achieved using FET's unilateral characteristics. Impedance matching is achieved using FET's active impedance matching function.



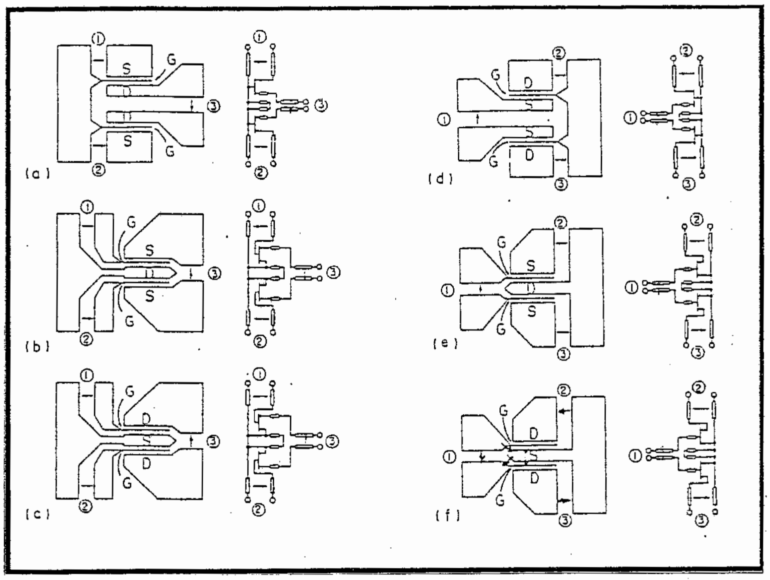
(OHP-7)

These are conventional power combiners: a Branch line hybrid and a Wilkinson combiner. These combiners are composed of several quarterwave length transmission lines which occupy a large area on the MMIC chip, and determine operation frequency range. LUFETs have the advantages of miniaturization and wideband operation.



(OHP-8)

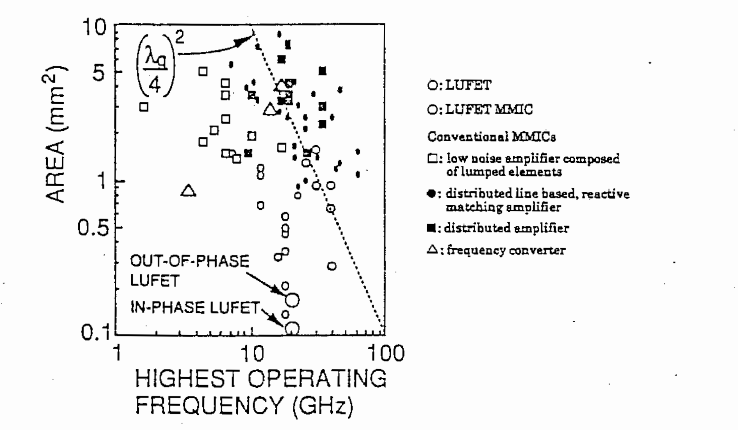
These are the LUFET families, in-phase combiners and in-phase dividers. Common gate configurations allow active impedance matching at the input ports. Common drain configurations allow active impedance matching at the output ports. Common source configurations have amplifiers.



(OHP-9)

LUFETs unified slotline series T-junctions produce out-of--phase combiners and out-of-phase dividers which can be applied to balanced circuits.

Chip-size Comparison of LUFET MMICs and Conventional MMICs



(OHP-10)

This figure compares the chip-size of LUFET MMICs and conventional MMICs. Red circles represent LUFET MMICs. Squares, dots and triangles represent conventional MMICs. As you can see, the LUFET MMIC achieves more than 3 times the circuit integration of the conventional MMIC.

Today's MENU of the LUFET MMIC

1. A Miniaturized, Ultra-wideband MMIC Magic-T.

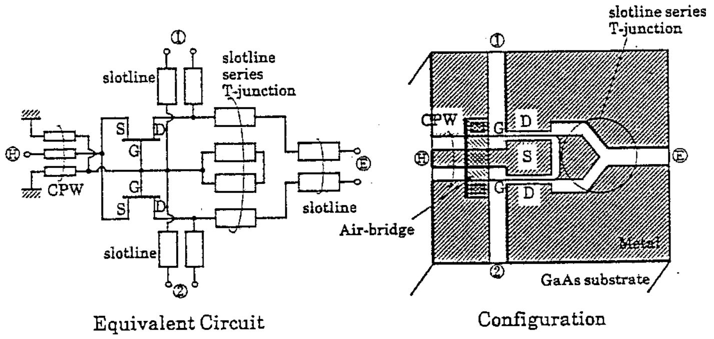
2. A Miniaturized, Ultra-wideband MMIC Frequency Doubler.

3. LUFET MMICs for L-band Active Array Antenna.

(OHP-11)

I'd like to introduce three LUFET MMICs developed in the last year. First, a LUFET magic-T. Next, a balanced frequency doubler using two LUFETs. Third, a L-band active array antenna sub-system using LUFET MMICs.

A Miniaturized, Ultra-wideband MMIC Magic-T

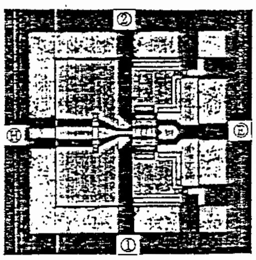


Equivalent Circuit   Configuration

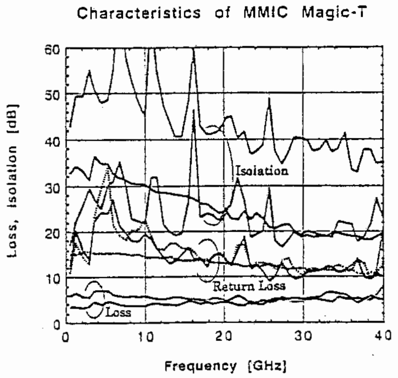
(OHP-12)

This is the configuration of the LUFET Magic-T. A Magic-T is usually composed of an out-of-phase and an in-phase power divider which have common output ports. This LUFET provides these dividers in an unique common-gate HEMT configuration by unifying a co-planar waveguide and a slotline series T-junction which operates as an out-of-phase divider. The coplanar waveguide composed of the gate-source-gate electrode is used for the input port of the in-phase power divider. Good isolation is expected between the Ⓔ and Ⓗ ports, because they have an anti-phase relationship. Ultra-wideband operation is expected for this configuration, as there are no frequency dependent elements.

A photomicrograph and chracteristics of MMIC Magic-T



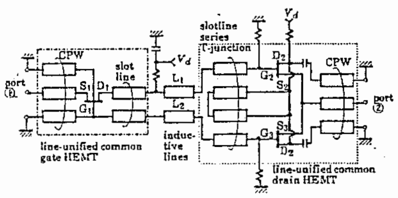
Chip size 0.8mm×0.8mm

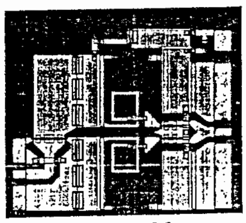


(OHP-13)

This is a photomicrograph of the fabricated LUFET Magic-T. The chip size is only 0.8mm ×0.8mm. The coupling loss is 6±2dB, return loss is better than 10dB, and isolation is better than 16dB form 1 to 40GHz.

A Miniaturized, Ultra-wideband MMIC Frequency Doubler

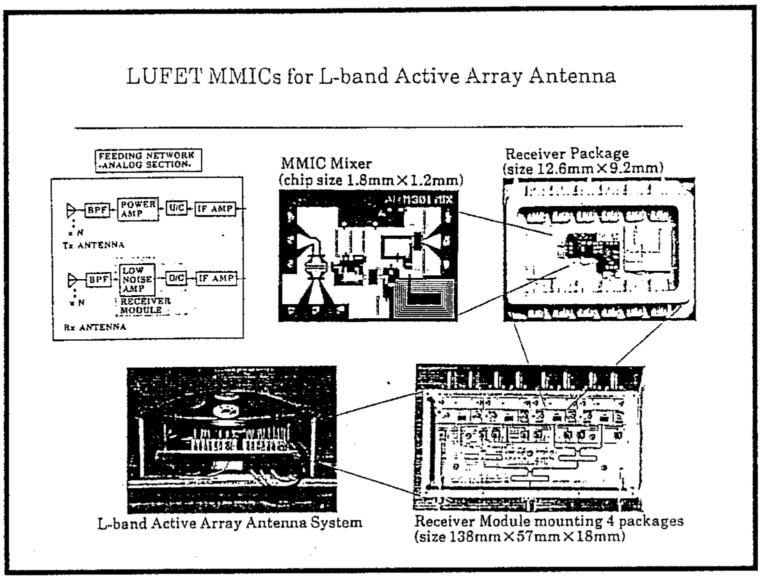




chip size: 1.0mm×0.9mm

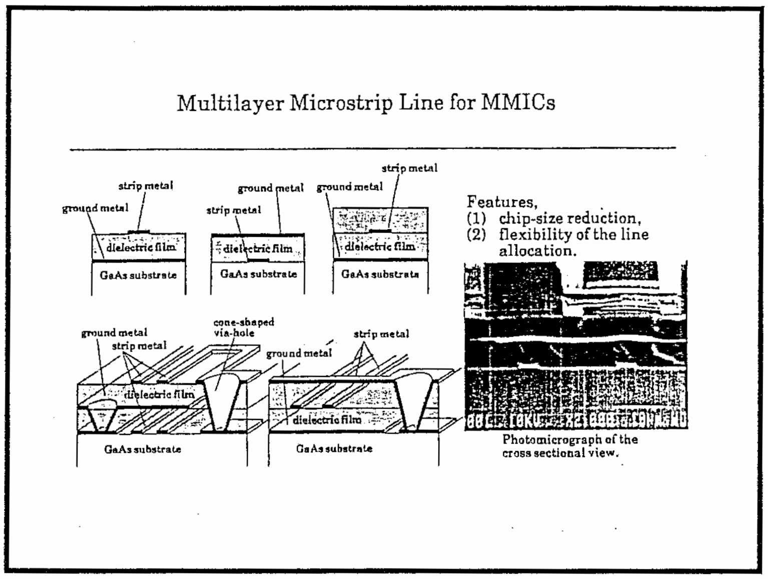
(OHP-14)

This is an MMIC balanced frequency doubler using a two line unified HEMT. A balanced frequency doubler is usually composed of an out-of-phase divider, two nonlinear devices and an in-phase combiner. In this doubler, the out-of-phase divider is achieved by unifying the slotline series T-junction with common drain HEMTs. The in-phase power combiner is also unified with the common drain HEMT electrode allocation. A line unified HEMT at the input stage is used for converting a co-planar waveguide to a slotline because slotline is required in the next stage. A fundamental signal is divided out-of-phase at this slotline series T-junction. These HEMTs are biased in a nonlinear state, so we can obtain fundamental signal harmonics at each source electrode of HEMT. Here, the source electrodes of the HEMTs are connected as the co-planar waveguide center conductor. Therefore, second harmonic signals are combined in-phase, and fundamental signal leakages cancel out. The chip is one fourth the size of a conventional MMIC balanced doubler.



(OHP-15)

This slide shows a L-band active array antenna sub-system using LUFET MMICs. The active array antenna makes good use of MMICs. It needs several repeatable circuit configurations, so, miniaturization is important for size and cost reductions. This is a receiver module mounted in the L-band active array antenna sub-system. Four packages are mounted on a module. A package contains two MMICs, an amplifier and a mixer. This is a LUFET MMIC Mixer. Four MMICs, a low noise amplifier, a down converter, a power amplifier and an up converter were designed for this system. The power combiner LUFET is applied to the down/up converters. Gain performance of the receiver package is 40dB, noise figure is 2dB.



(OHP-16)

The next topic is the multilayer MMIC. In the multilayer MMIC, thin dielectric film and metal layers are alternately stacked onto the GaAs substrate. These are cross sectional views of multilayer microstrip lines. They are constructed using ground metal, dielectric film and strip metal. Since the dielectric film is much thinner than the GaAs substrate, miniaturized microstrip lines are possible. Conventional MMICs use a 100μm thick GaAs substrate as the microstrip line substrate. However, the dielectric film is only 5 to 10μm thick. Thus, the width of the microstrip line is one tenth of that of conventional MMICs. Furthermore, we can place a microstrip line on another microstrip line. Stacked microstrip lines are shown. In the left hand structure, the ground metal plane between the dielectric films completely isolates the upper and lower layers. In the right hand structure, we can cross the microstrip lines over, because the lines are too narrow to couple. These structures provide greater miniaturization and flexibility for the allocation of circuit elements. This is a cross sectional photomicrograph of the multilayer structure.

Polyimide for thin dielectric films

(1) the chemical-etching of the polyimide film allows the cone-shaped via-hole which prevents metal-disconnect in the via-hole even if the thickness of the substrate is large enough,

(2) the polyimide film formed by spin-coating has a flat surface even if the lower layer has some irregularities generated by the circuit pattern,

(3) a uniformity in thickness of better than 1% up to a thickness of 10μm,

(4) the film stress is one-tenth that of Si_3N_4 and SiO_2 films'.

(OHP-17)

We are using polyimide for the dielectric film material, due to the features shown here. First, chemical-etching of the polyimide film allows the cone-shaped via-hole which prevents metal-disconnection in the via-hole even if the substrate is thick enough. Second, the polyimide film formed by spin-coating is flat even if the lower layer has some irregularities generated by the circuit pattern. Third, it has an uniform thickness better than 1% up to a thickness of 10μm. Fourth, film stress is one-tenth of that of Si_3N_4 and SiO_2 films.

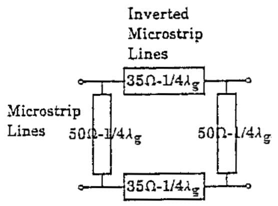
Today's MENU of the Multilayer MMICs

1. Multilayer MMIC Branch Line Hybrid
2. Multilayer MMIC Balanced Amplifier
3. Multilayer MMIC Image Rejection Mixer
4. Multilayer MMIC Balanced Up-converter

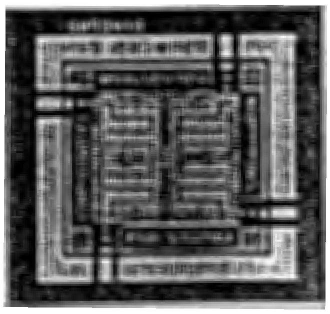
(OHP-18)

Four multilayer MMICs will be presented. A branch line hybrid, a balanced amplifier, an image rejection mixer and a balanced up-converter. The image rejection mixer and the balanced up-converter are also using a line unified HEMT.

Multilayer 20GHz Branch Line Hybrid



Equivalent Circuit

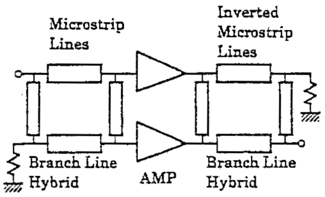


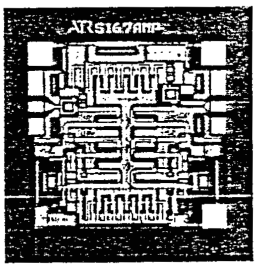
chip size: 0.95mm×0.91mm

(OHP-19)

This is an equivalent circuit of the branch line hybrid. It consists of four quarter wave length transmission lines, two 50ohms and two 35ohms lines. By using the multilayer structure, 50ohms lines are stacked onto the 35ohms lines. The chip is one fourth the size of the conventional branch line hybrid.

Multilayer 30GHz Balanced Amplifier

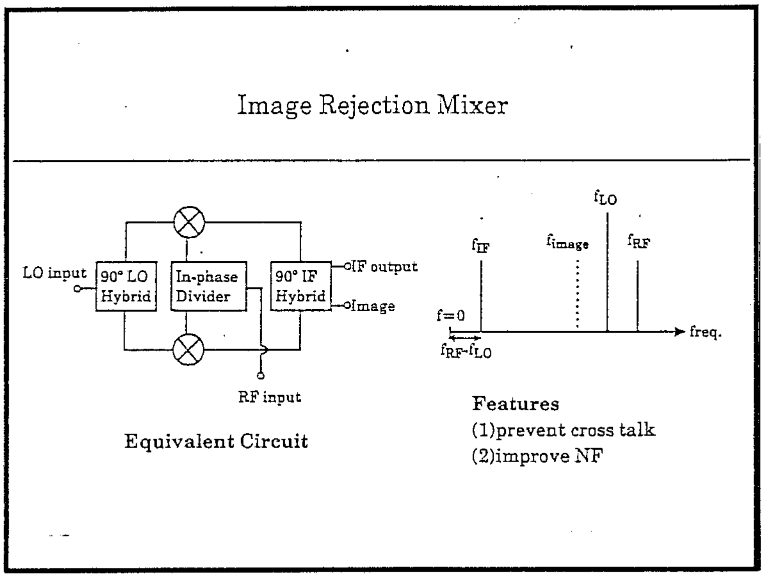




chip size: 0.8mm×0.8mm

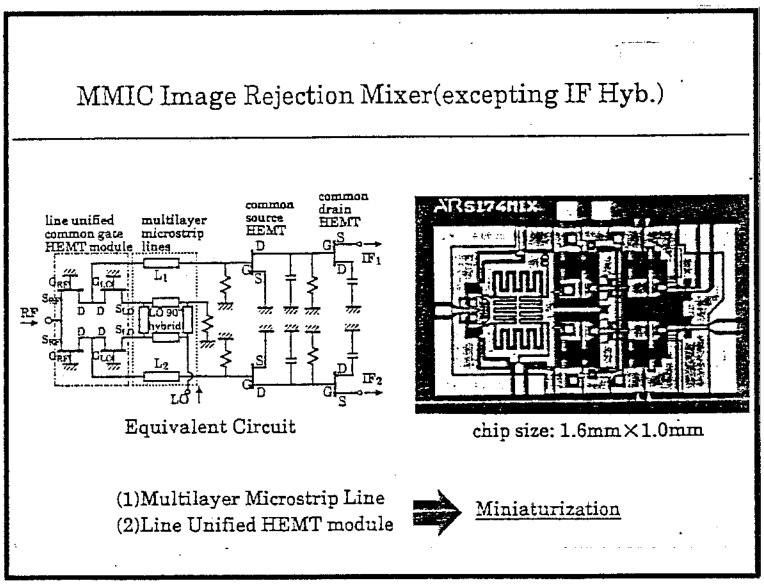
(OHP-20)

This is a multilayer balanced amplifier. By using the multilayer structure, the branch line hybrid at the input stage is stacked onto another branch line hybrid at the output stage. The chip is only 0.8mm× 0.8mm.



(OHP-21)

Generally, an image rejection mixer consists of a 90 degree LO hybrid, an in-phase RF power divider, two mixers and a 90 degree IF hybrid. It attenuates input without filters at the image frequency. By rejecting the image, it prevents crosstalk and reduces noise figure.



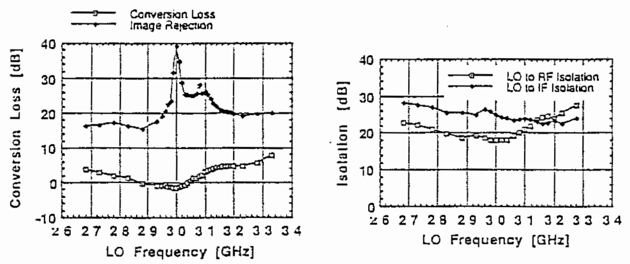
(OHP-22)

This is an image rejection mixer using a multilayer structure and a line unified HEMT. The inductive lines are stacked onto the branch line hybrid. A line unified HEMT module which provides RF dividing, RF/LO combining, input port isolation and matching, is used for the RF input. The combined RF/LO signals are mixed down in common source HEMTs biased in a nonlinear state. Isolation from the LO to the IF ports is achieved using high loaded-Q low pass filters composed of capacitances C_1, C_2 and common drain HEMTs. The common drain HEMTs also provide active impedance matching at the output ports. The chip is only 1.6mm×1.0mm.

(OHP-23)

These are measured characteristics of the image rejection mixer. At 30GHz, the image rejection ratio is about 40dB, and conversion loss is better than 0dB. Isolation from the LO to IF ports is better than 20dB.

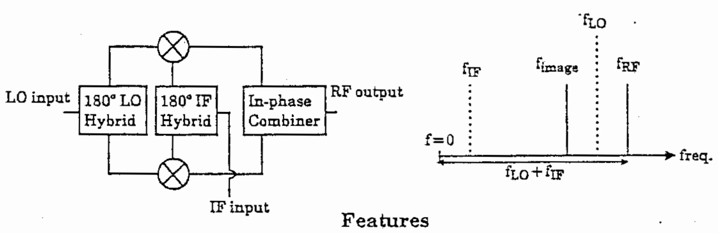
Characteristics of MMIC Image Rejection Mixer



(OHP-24)

This is a block diagram of a balanced up-converter. It consists of a 180 degree LO hybrid, a 180 degree IF hybrid, two mixers and an in-phase RF combiner. It suppresses LO signal leakage at the RF port to prevent saturation at the next stage.

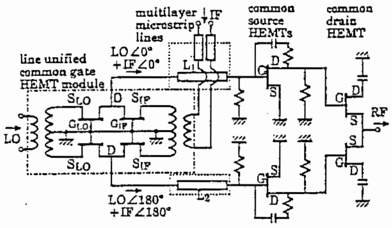
Balanced Up-converter



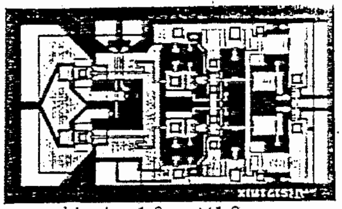
Equivalent Circuit

Features
(1)suppress LO signal leakage at RF port
(2)suppress IF signal leakage at RF port

MMIC Balanced Up-converter(excepting IF Hyb.)



Equivalent Circuit



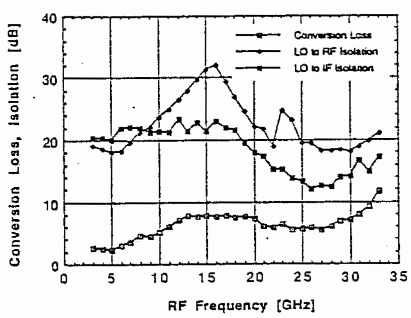
chip size: ~~1.6~~mm × ~~1.0~~mm
1.7 0.9

(1)Multilayer Microstrip Line
(2)Line Unified HEMT module
→ Miniaturization
Wideband Operation

(OHP-25)

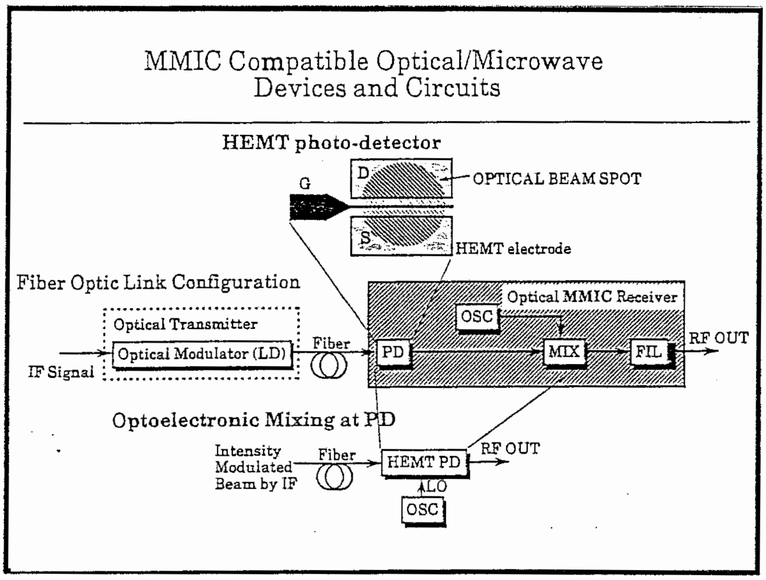
This is a balanced up-converter using the multilayer structure and a line unified HEMT. The multilayer structure is used for inductive and IF input lines crossover. The line unified HEMT at the LO input stage provides LO dividing out-of-phase, LO/IF combining, isolations between the LO and IF input ports and input impedance matching. Combined LO/IF signals are mixed up in common source HEMTs biased in a non-linear state. RF signals are combined in-phase and LO/IF leakage signals cancel each other in a common drain HEMT at the output stage. The fabricated chip is 1.7mm×0.9mm.

Characteristics of MMIC Balanced Up-converter



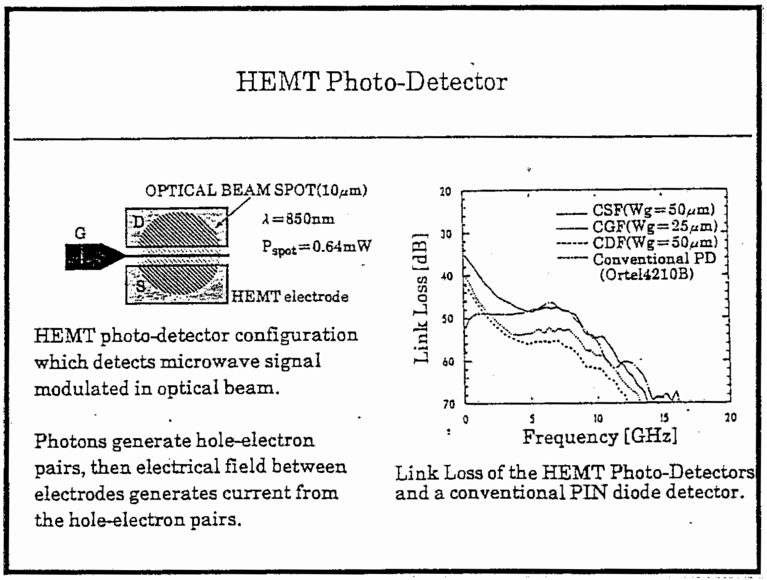
(OHP-26)

These are the measured characteristics of the balanced up-converter. From 3 to 31GHz, conversion loss is better than 8dB, LO to RF ports isolation is better than 18dB. LO to IF ports isolation is better than 12dB.



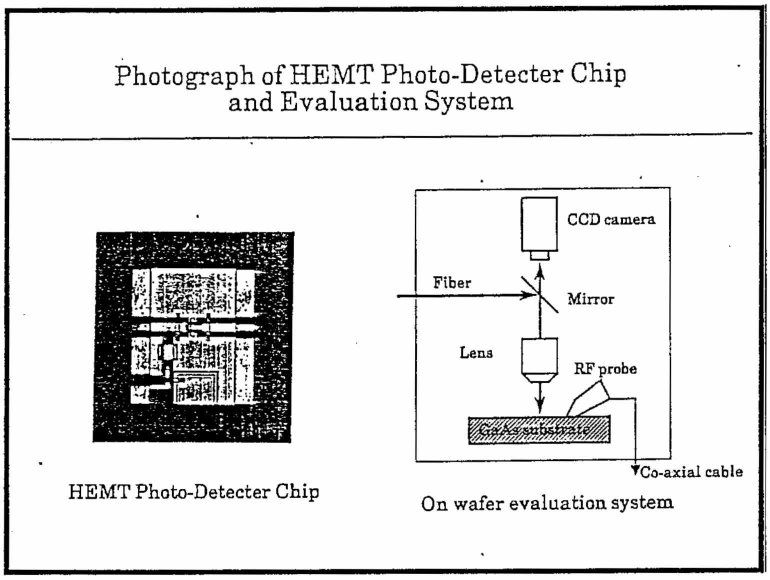
(OHP-27)

This slide summarizes MMIC compatible optical/microwave devices and circuits which have been developed at ATR. We proposed the conventional HEMTs photo detector operation. PIN diodes are usually used for photo detectors. However, it is difficult to fabricate PIN diodes on GaAs MMIC chip. By using HEMTs as photo detectors, an optical MMIC receiver like this can be easily created. Furthermore, by driving the HEMT photodetector with a LO signal, it also operates as a mixer. In this case, the HEMT photo-detector operates as an up-converter.



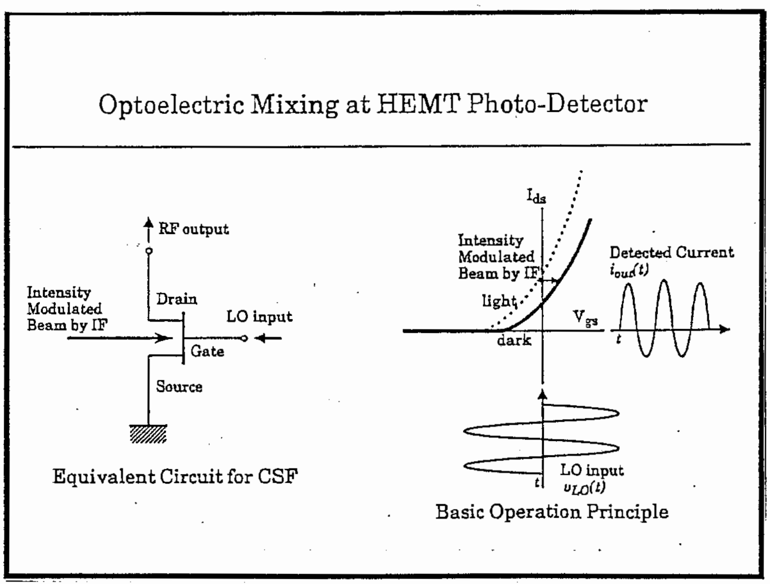
(OHP-28)

This is the HEMT photo-detector configuration which detects the microwave signals modulated in an optical beam. This graph shows the link loss of the HEMT detector and the conventional photo detector, when the beam spot diameter is 10μm and optical wavelength is 850nm. Up to 5GHz, the common source HEMT performs better than the conventional photodetector. From 5 to 8GHz, the performance of both levels out.



(OHP-29)

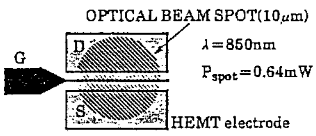
This is a photomicrograph of the HEMT photo detector. The fabrication process is the same as that of the MMICs. This is an evaluation system for the HEMT photo detector. This measurement system is very reliable as it has a fine z-axis positioner and a monitoring CCD camera.



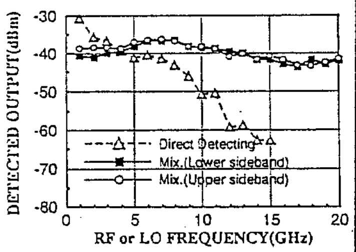
(OHP-30)

This slide shows the basic principle of HEMT optoelectronic mixing. By focusing an intensity modulated beam onto the HEMT electrode and feeding a LO signal to the gate, the mixed-up is performed in the HEMT and the RF signal can be obtained from the drain. Mixing-up is generated by the nonlinearity of the HEMT.

Frequency Response of HEMT Optoelectronic Up-converting



(1) simplification of the optical MMIC receiver chip.
(2) application for image rejection or balanced mixers.
(3) combination with LUFET configuration andmultilayer structure.



(OHP-31)

This slide shows the frequency response of the HEMT optoelectronic up-converting. Performance is stable up to 20GHz RF output. HEMT optoelectronic mixing simplifies the optical MMIC receiver chip. Furthermore, optoelectronic image rejection and balanced mixer are possible. LUFET and the multilayer structure will be really available when designing such mixers.

Conclusion

1. Line Unified FET and Multilayer structures.
2. Miniaturized MMICs utilizing LUFET and Multilayer structures
3. HEMT photo detectors and its optoelectric mixing.

(OHP-32)

In conclusion, I have presented MMIC technologies, Line-Unified FET (LUFET) and multilayer structures, which remarkably reduce MMIC chip-size. I have also presented some miniaturized MMIC utilizing LUFET and multilayer microstrip lines. Novel HEMT applications such as photo detectors and optoelectronic mixing which could be fabricated onto an MMIC chip, were also introduced.