National Central University

Device Model Extraction of Near-Ballistic Transport UTC Photodiode (NBUTC)

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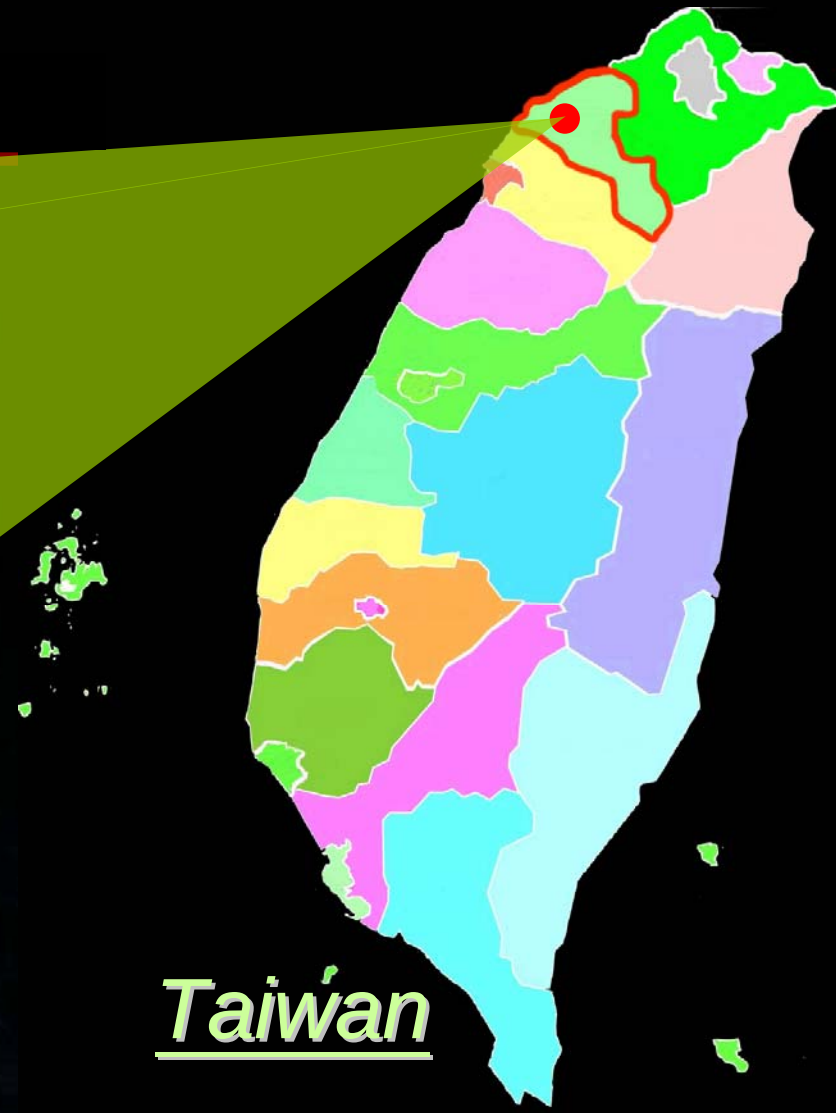
Solid stste & Microwave Laboratory
Super Photonic & Electronic Device Group (SPED Group)

National Central University



Taiwan

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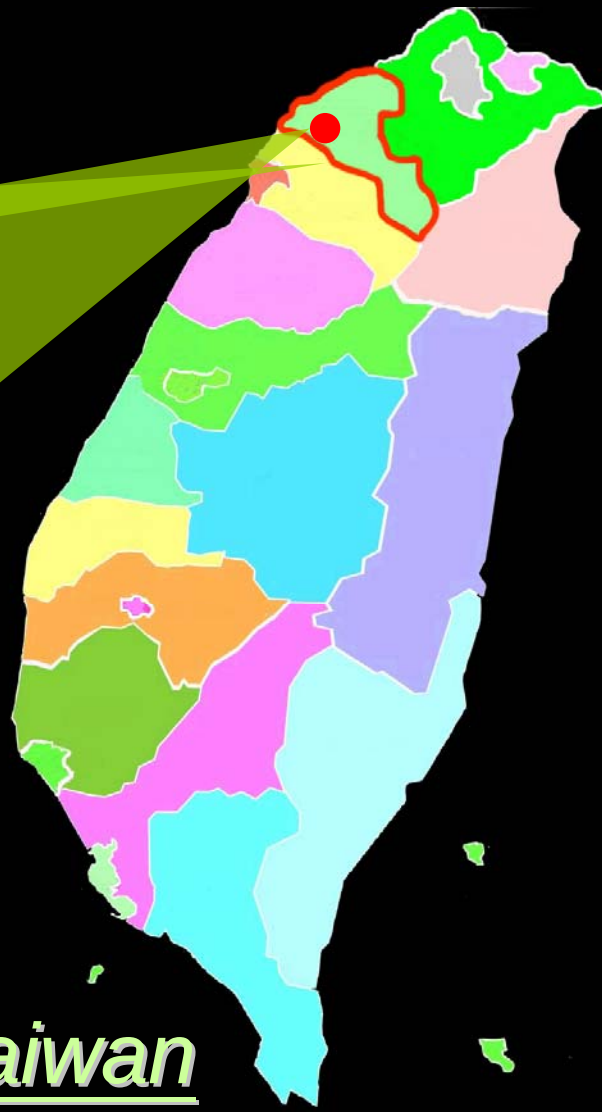
國立中央大學 電機工程學系
NATIONAL CENTRAL UNIVERSITY
DEPARTMENT OF ELECTRICAL ENGINEERING

Micro-Optoelectronic Labs



Taiwan

Superfast Photonic &
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Outline

I. Motivation

II. The Structure of BUT-CPD

III. Measurement System

IV. Model Extraction

V. The Fitting Results

VI. Conclusions

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Transmitter for Fiber-Radio Communication System

- The loss of electrical signal can be reduced through wireless communication system.
- To simplify the base station by eliminating the costly post amplifiers and cables.

Transmitter Module

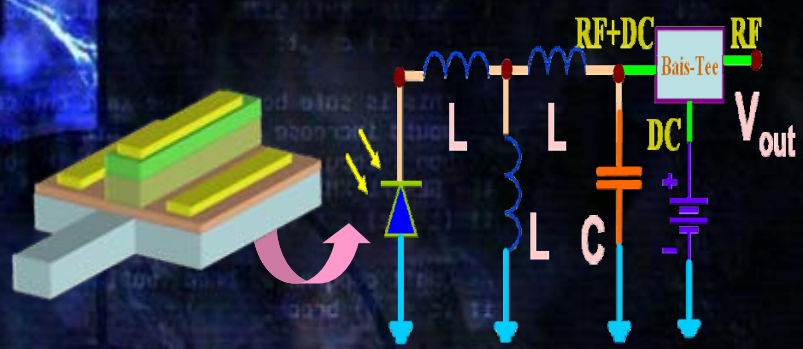
Photodiode Matching Circuit Antenna

Transmitter for Fiber-Radio Communication System

- The loss of electrical signal can be reduced through wireless communication system.
- To simplify the base station by eliminating the costly post amplifiers and cables.

The model extraction of PD serves as a key approach to design the transmitter module

Transmitter Module



Mm-Wave Detector

Photodiode Matching Circuit Antenna

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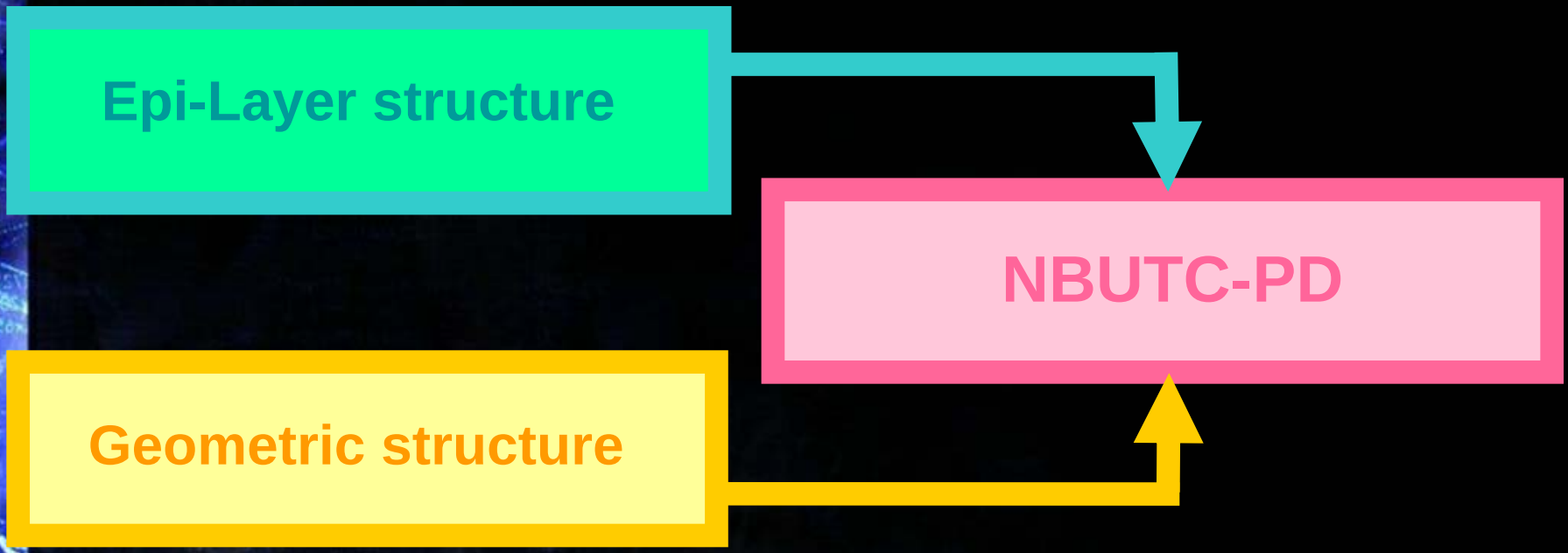
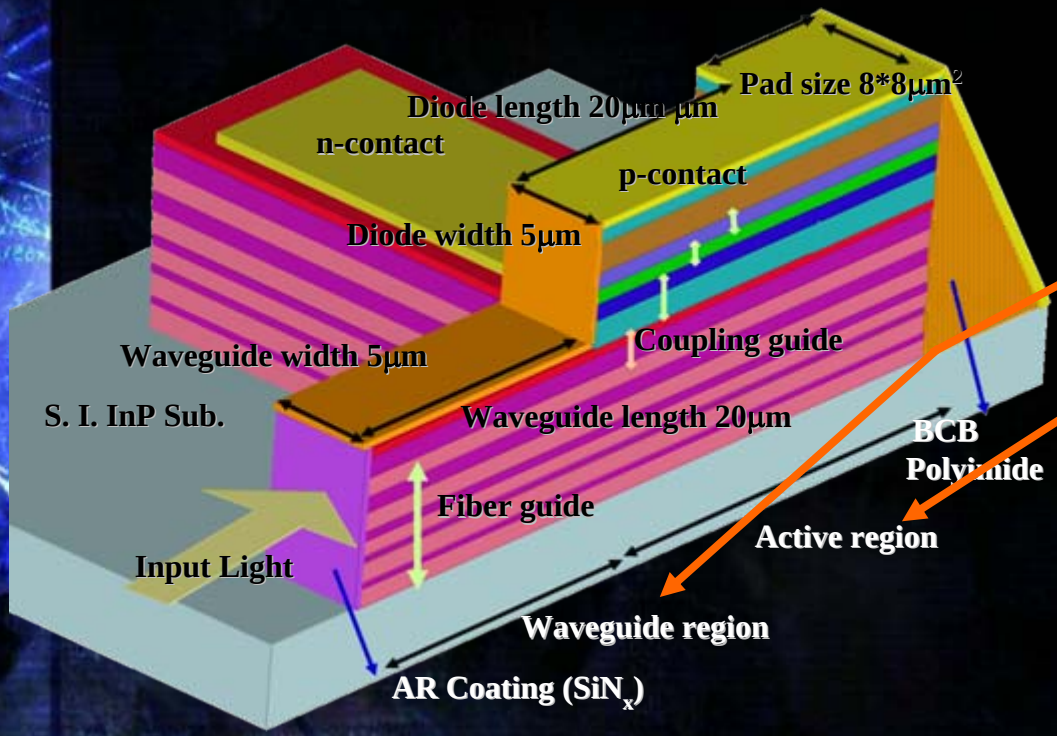
How We Design the Structure?

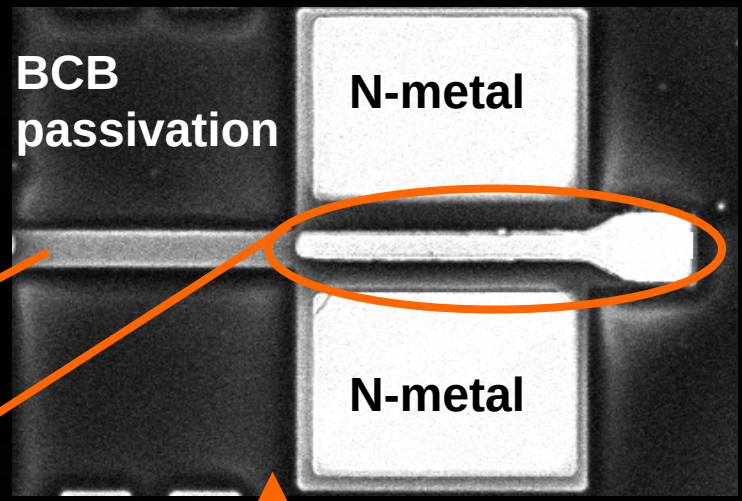


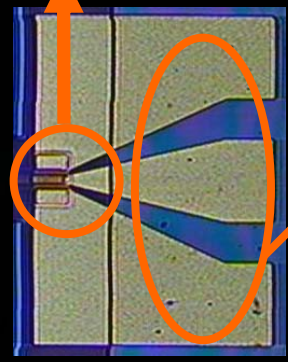
- Epi-layer structure: Near-Ballistic Transport
- Geometric structure: Evanescently coupled waveguide
- NBUTC-PD: Three major target can be achieved simultaneously

Our Structure !!

NBUTC-PD with Evanescently coupled optical waveguide structure







20μm<<700μm of ATW!!

F. Xia, et. al , *IEEE Photon. Technol. Lett.*, vol.13, Aug., 2001.

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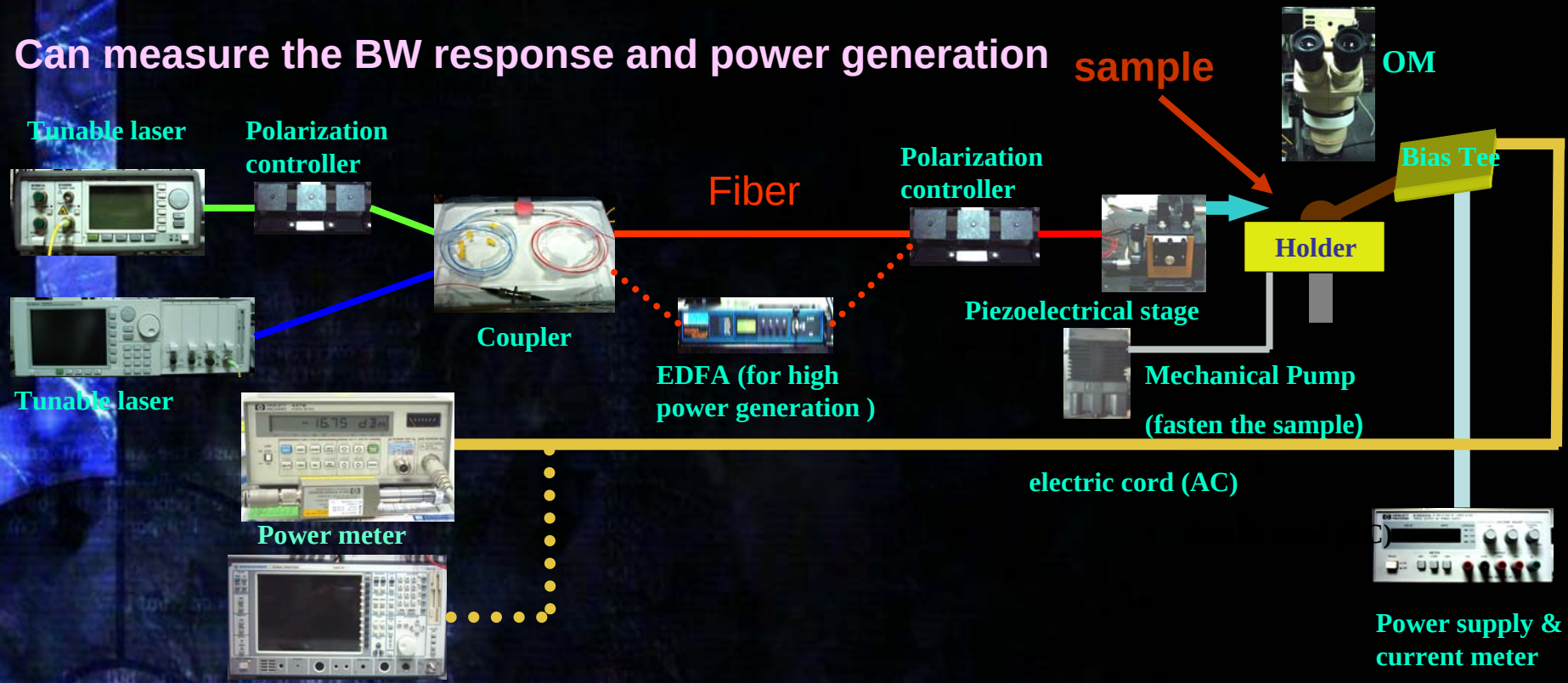
Heterodyne-Beating Measurement Setup (Large Signal Measurement)

By increasing the wavelength difference, the bandwidth response is available through recording the amplitude of RF tone signal.

Can measure the BW response and power generation



LNA Measurement Setup (Small Signal Measurement)

Not only measure amplitude response but also phase response

1. Calibrate the packaged Modulator and save as s2p file
2. Don't change the bias voltage & polarization of the Modulator
3. De-embedded the Modulator

Step 1

Step 2

Lightning Network Analyzers

Power supply

Tunable Laser

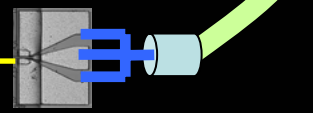
Port 2

Polarization Controller

EDFA

Modulator

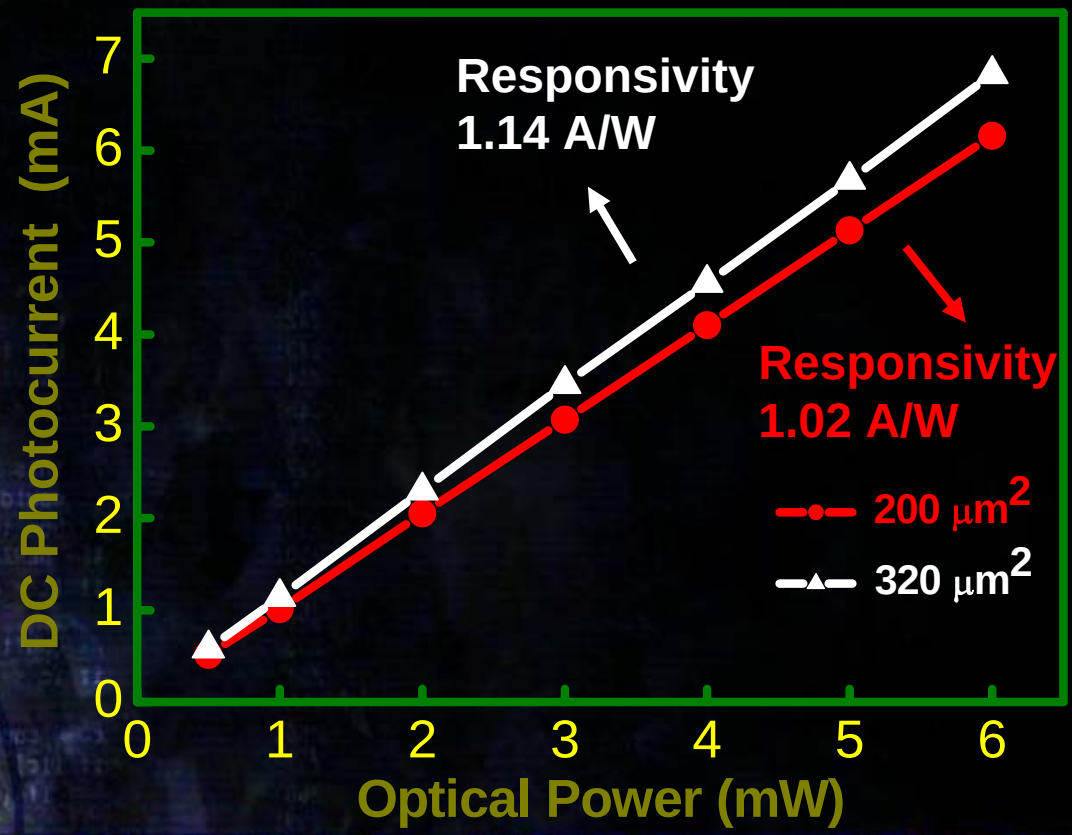
Polarization Controller



Anritsu 37300C VNA + MN4765A (commercial PD)

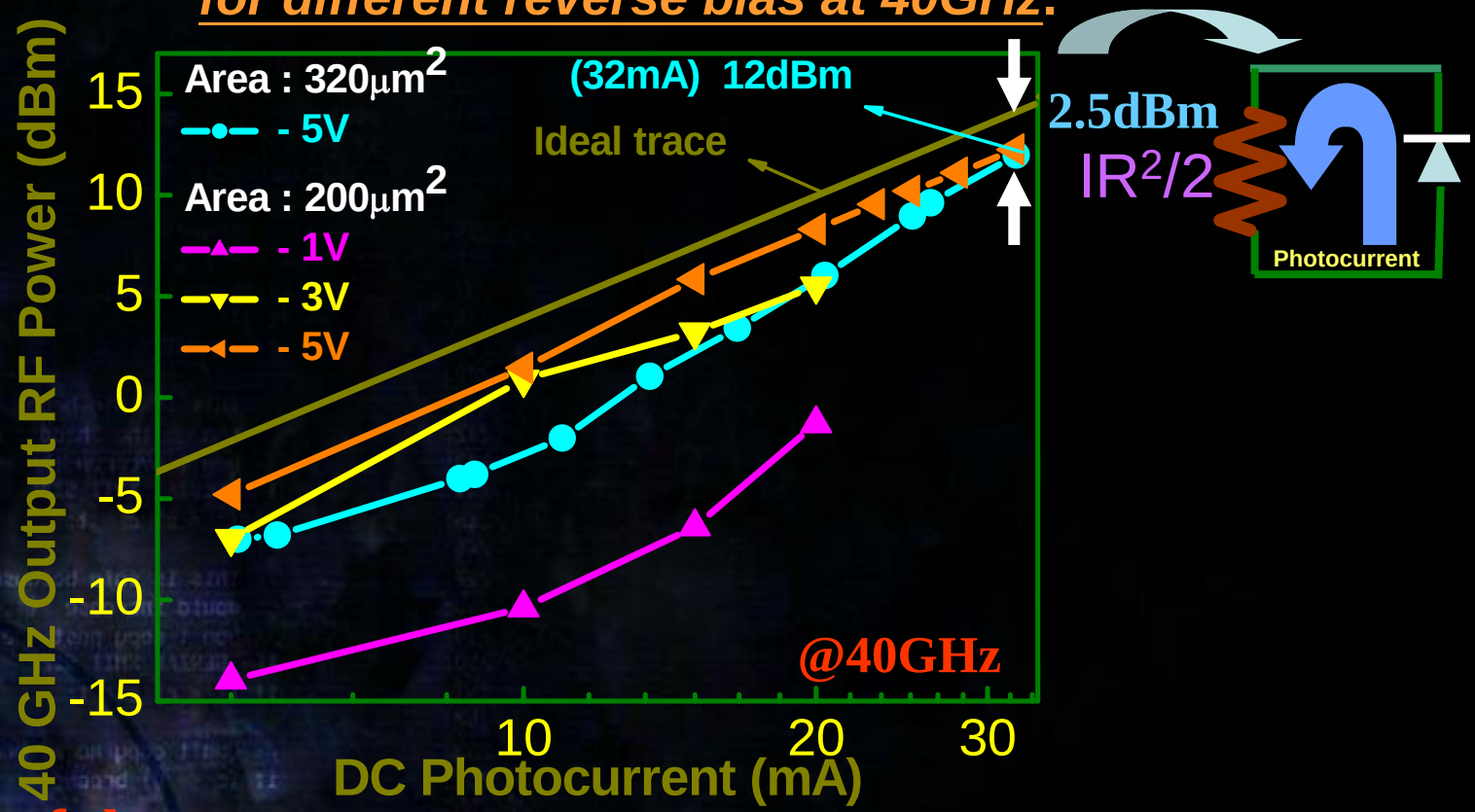
Responsivity

The measured photocurrent vs. optical pumping power. Very high responsivity (1.14 A/W) of our device can be achieved.



Excellent Performance of RF Power Generation

RF power versus dc photocurrent for different reverse bias at 40GHz.

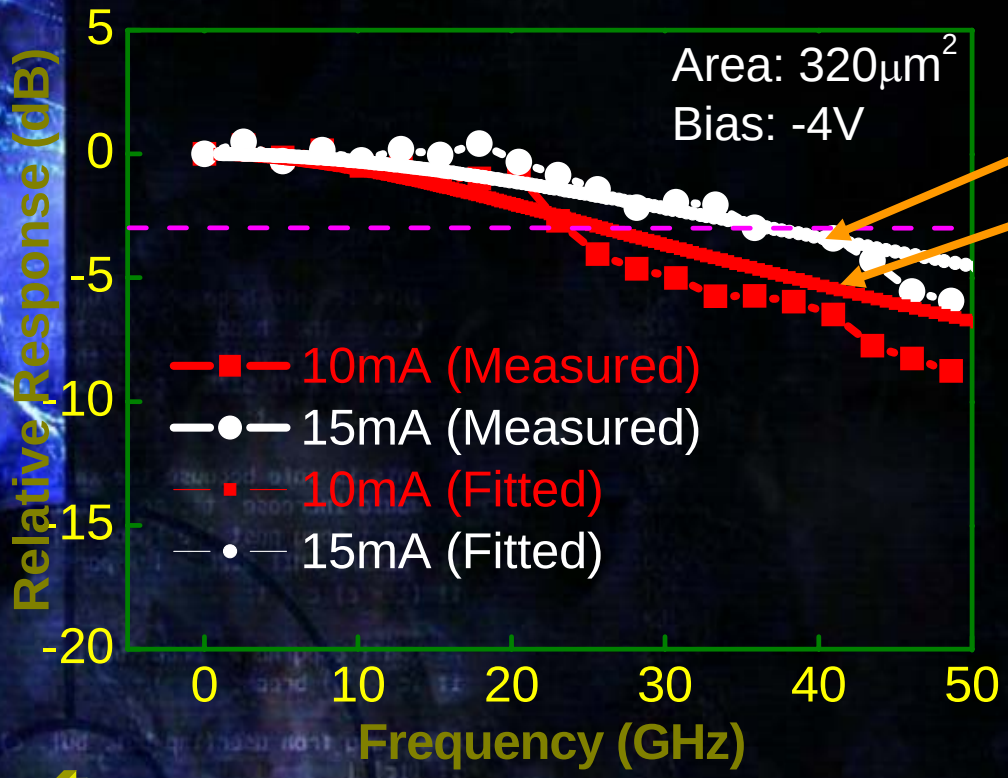


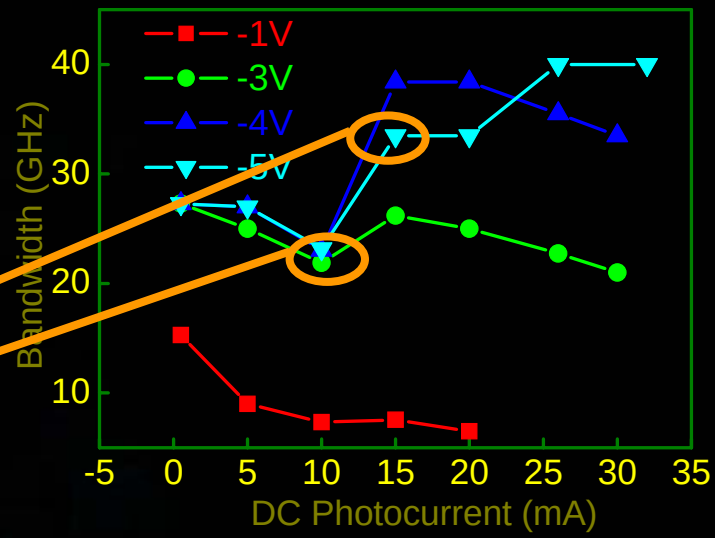
State of the art: ***1.14A/W Responsivity, 40GHz Bandwidth, 1280mA Current-Bandwidth Product can be achieved simultaneously***

Electrical Bandwidth-(Ballistic & Non-Ballistic Transport)

40GHz 3dB bandwidth for OC-768 Communication system !!

Obvious nonlinear effect !!





Fitted Electron Velocity (10mA):

1×10^7 cm/sec

Fitted Electron Velocity (15mA):

4×10^7 cm/sec

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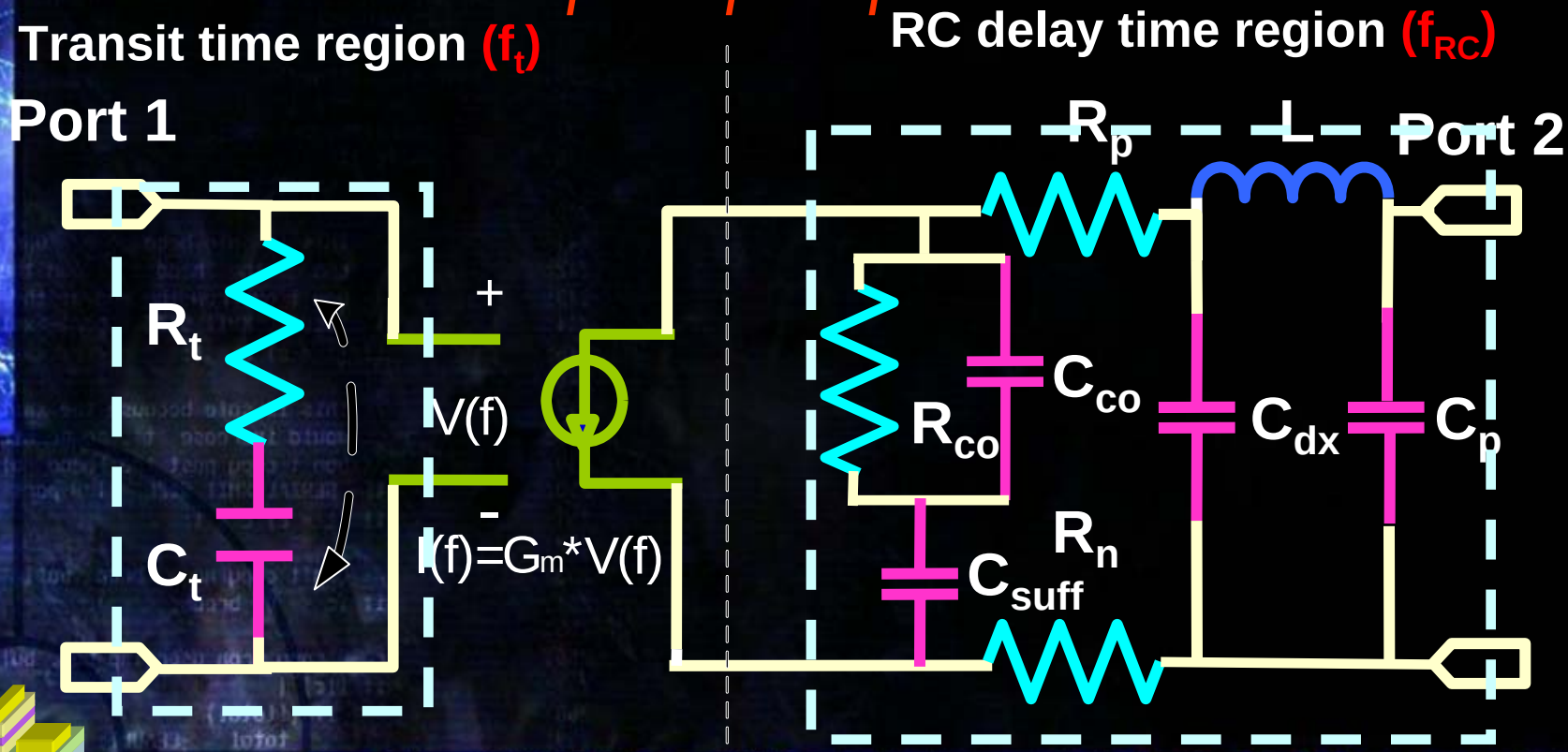
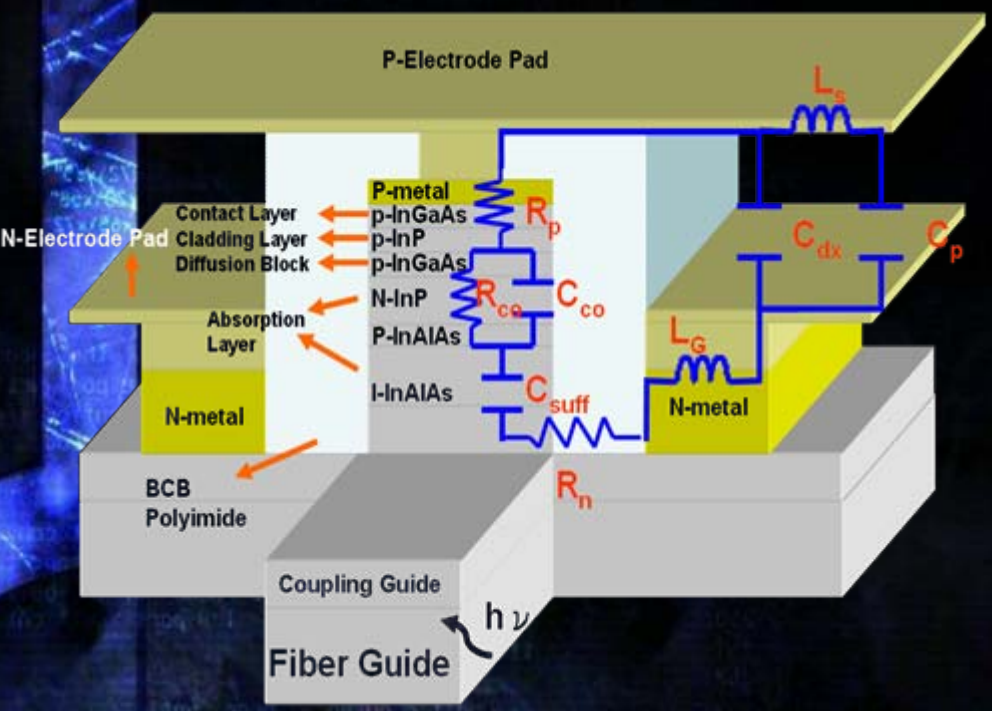
The Equivalent Circuit Model (I)

RC or Carrier-Transport-Effect ?!

$$\frac{1}{f_{3dB}^2} = \frac{1}{f_{RC}^2} + \frac{1}{f_t^2}$$



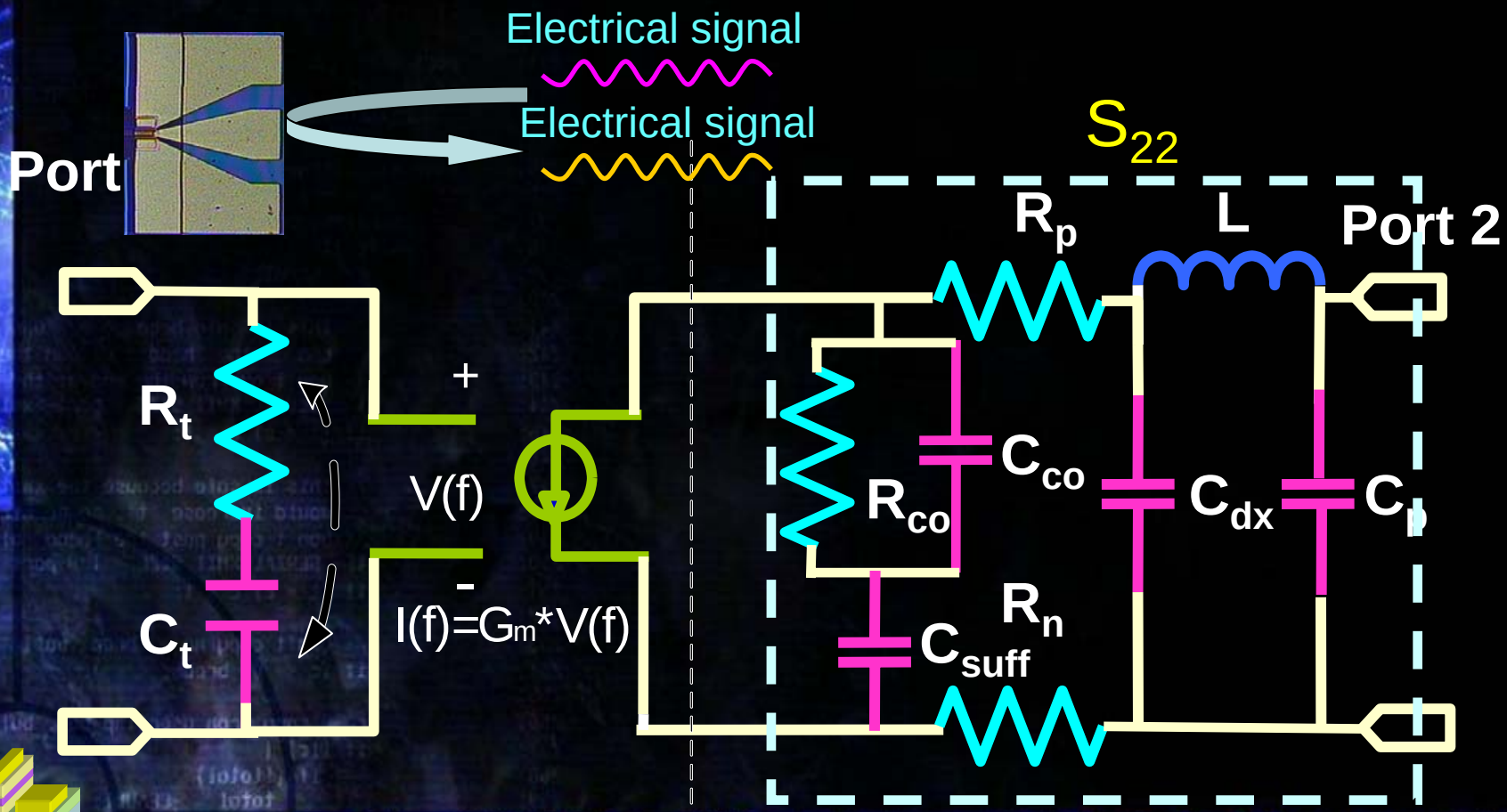
The Definition of Parameters in This Equivalent Circuit



Rp	P-Contact + P-absorption layer resistance
Rn	N-Contact resistance
Rco	Collector layer resistance
Cco	Collector layer capacitance
Csuff	Suffer layer capacitance
Cdx	BCB Capacitance
Cp	Pad Capacitance
Lg	Inductance of Contact Metal
Ls	Inductance of Pad

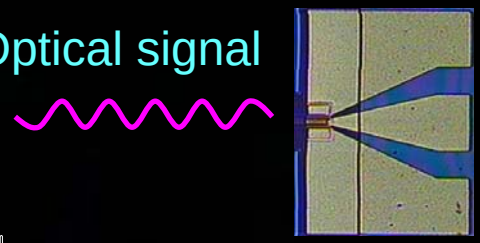
The Equivalent Circuit Model (II)

S_{22}: Microwave Refection Coefficients (RC)



The Equivalent Circuit Model

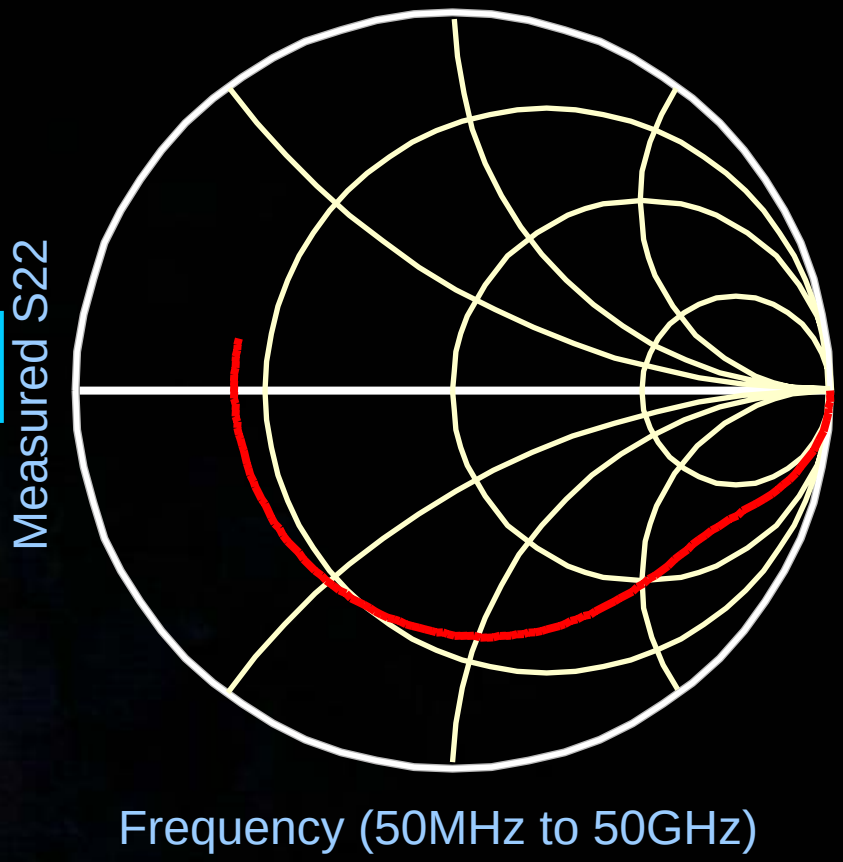
S_{21}: Net OE Bandwidth (Carrier Transport and RC)



The Step of Model Extraction!!

Part 1 : Determine right hand of equivalent circuit

Measure the S_{22} parameters of BUTC-PD

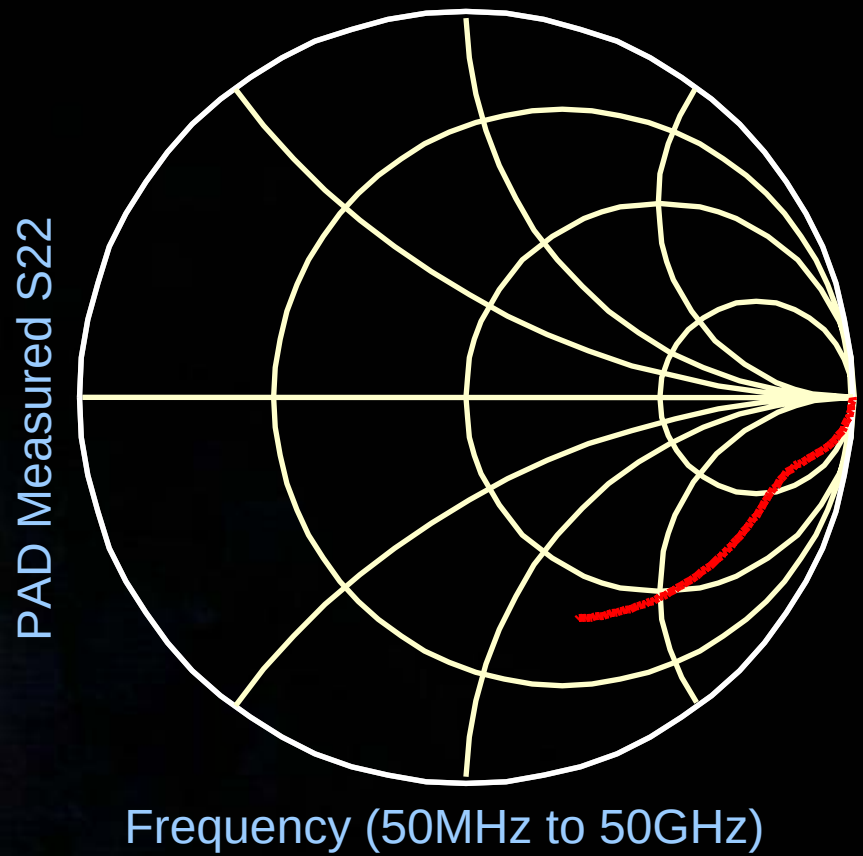


The Step of Model Extraction!!

Part 1 : Determine right hand of equivalent circuit

Measure the S_{22} parameters of BUTC-PD

Measure the S_{22} parameters of coplanar electrical pad

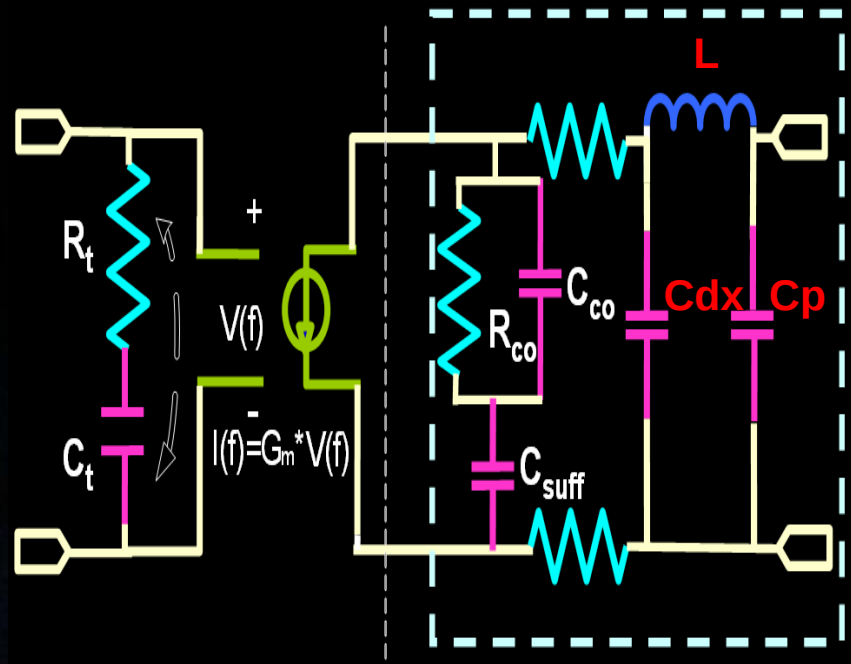


The Step of Model Extraction!!

Part 1 : Determine right hand of equivalent circuit

Measure the S_{22} parameters of BUTC-PD

Measure the S_{22} parameters of coplanar electrical pad (L, Cdx, Cp)



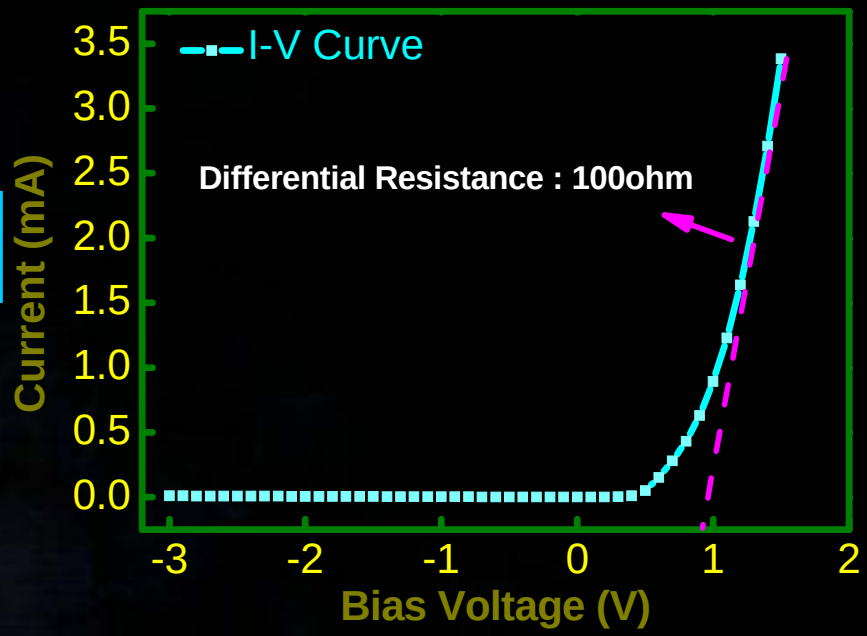
The Step of Model Extraction!!

Part 1 : Determine right hand of equivalent circuit

Measure the S_{22} parameters of BUTC-PD

Measure the S_{22} parameters of coplanar electrical pad (L, Cdx, Cp)

Perform the I-V measurement



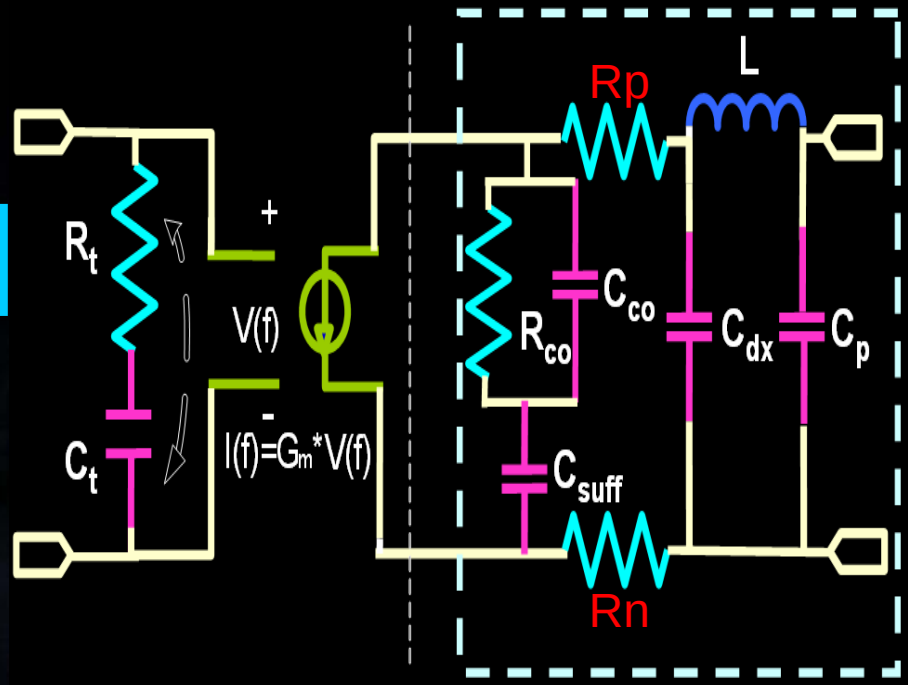
The Step of Model Extraction!!

Part 1 : Determine right hand of equivalent circuit

Measure the S_{22} parameters of BUTC-PD

Measure the S_{22} parameters of coplanar electrical pad (L, Cdx, Cp)

Perform the I-V measurement (Rp, Rn)



The Step of Model Extraction!!

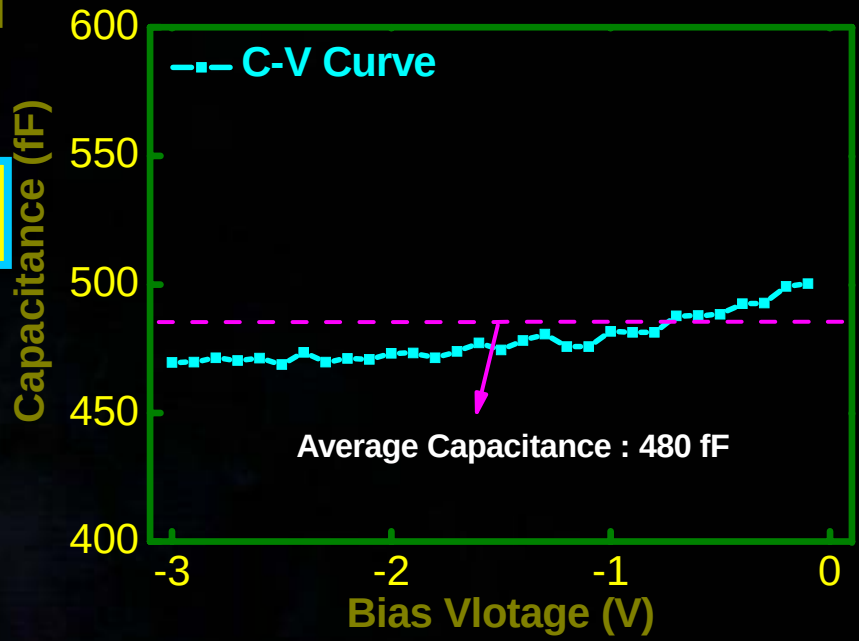
Part 1 : Determine right hand of equivalent circuit

Measure the S_{22} parameters of BUTC-PD

Measure the S_{22} parameters of coplanar electrical pad (L, Cdx, Cp)

Perform the I-V measurement (Rp, Rn)

Perform the C-V measurement (total capacitance)



The Step of Model Extraction!!

Part 1 : Determine right hand of equivalent circuit

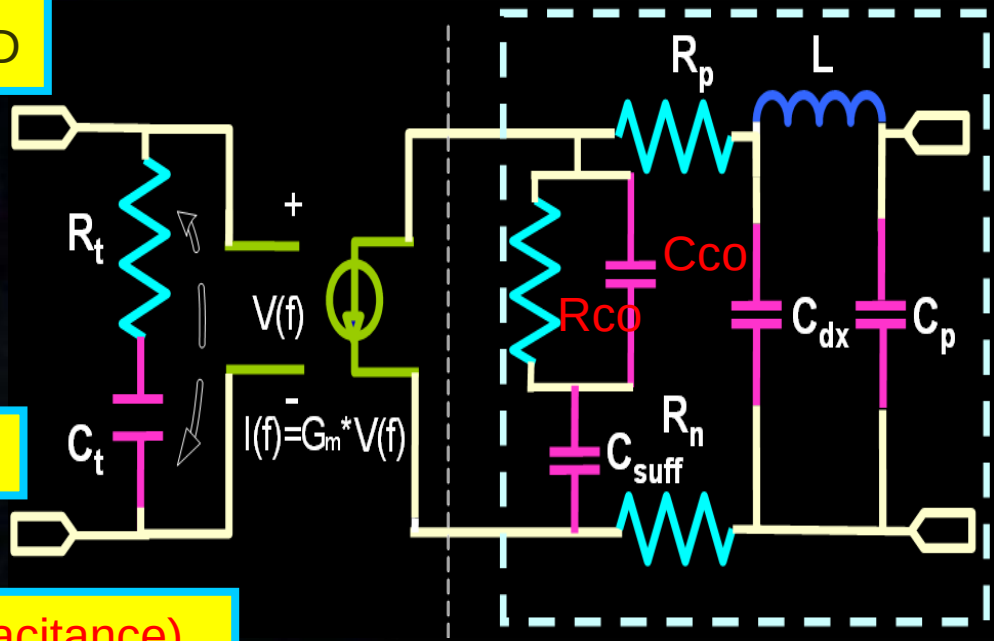
Measure the S_{22} parameters of BUTC-PD

Measure the S_{22} parameters of coplanar electrical pad (L, Cdx, Cp)

Perform the I-V measurement (Rp, Rn)

Perform the C-V measurement (total capacitance)

Fitting the measured S_{22} parameters (Rco, Cco)



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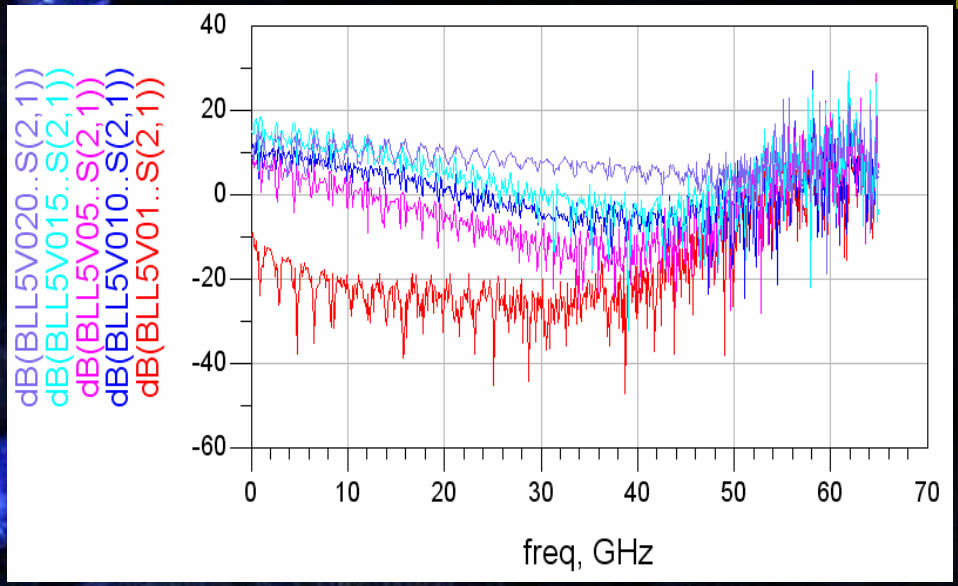
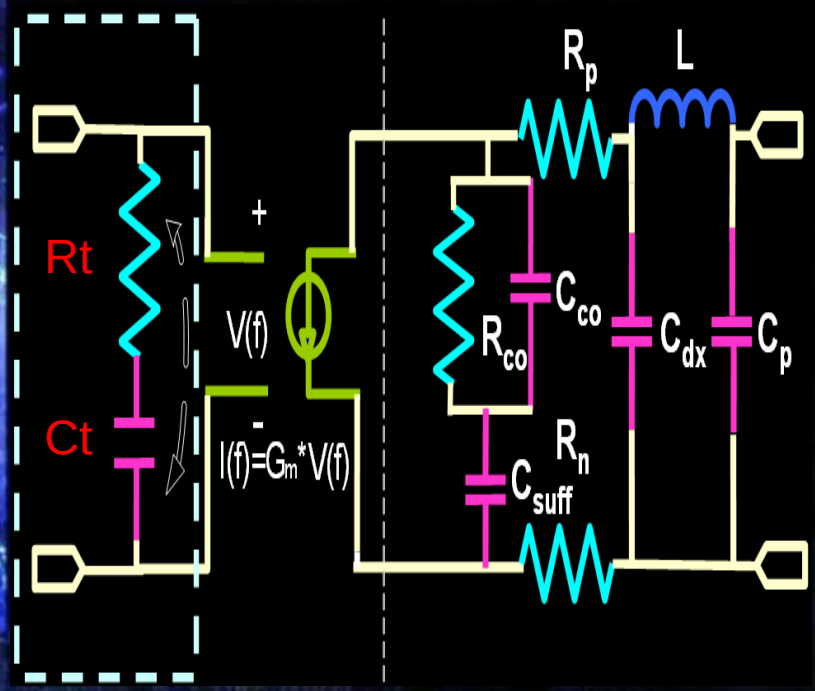


Part 2 : Determine left hand of equivalent circuit

Measure the S_{21} parameters of BUTC-PD under different photocurrent and bias voltage

The Step of Model Extraction!!



Part 2 : Determine left hand of equivalent circuit

Measure the S_{21} parameters of BUTC-PD under different photocurrent and bias voltage

Fit the S_{21} parameters under different bias voltage and photocurrent (Rt, Ct)

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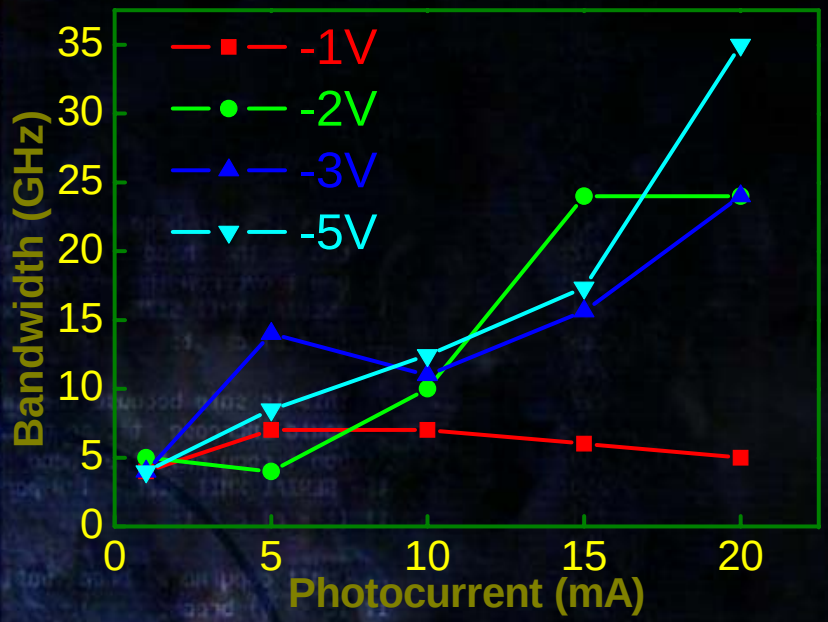
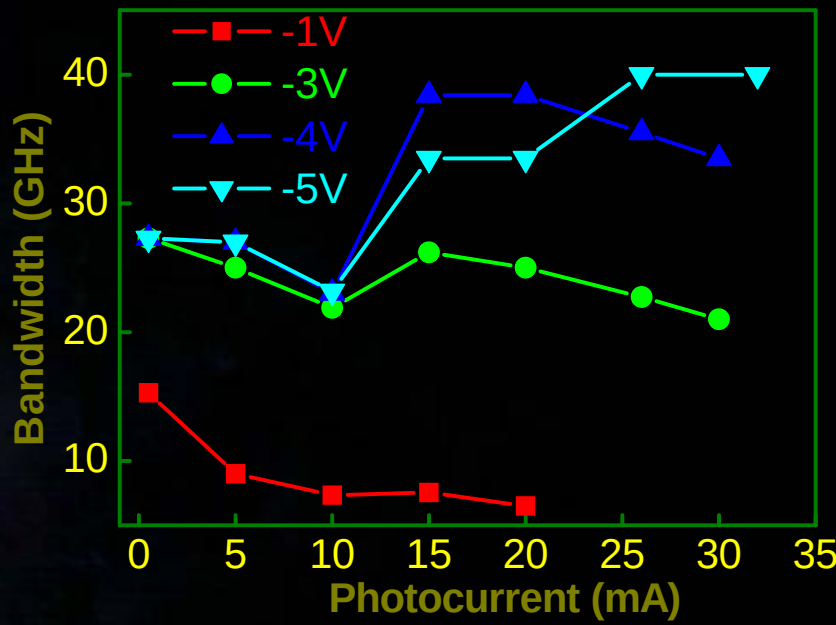
The Bandwidth Enhancement !?

Bandwidth increases with output photocurrent !! ?

Contrary with Space-Charge Screening Effect ?!



LNA setup



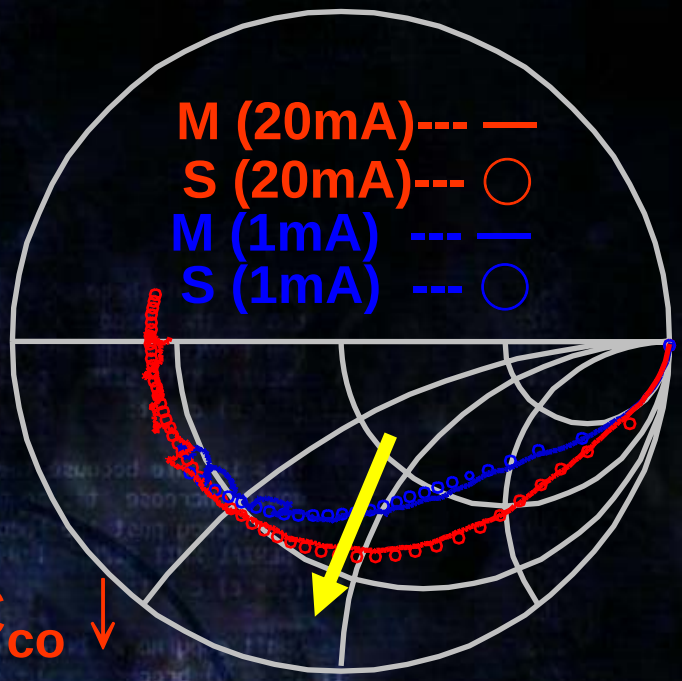
Heterodyne Beating setup

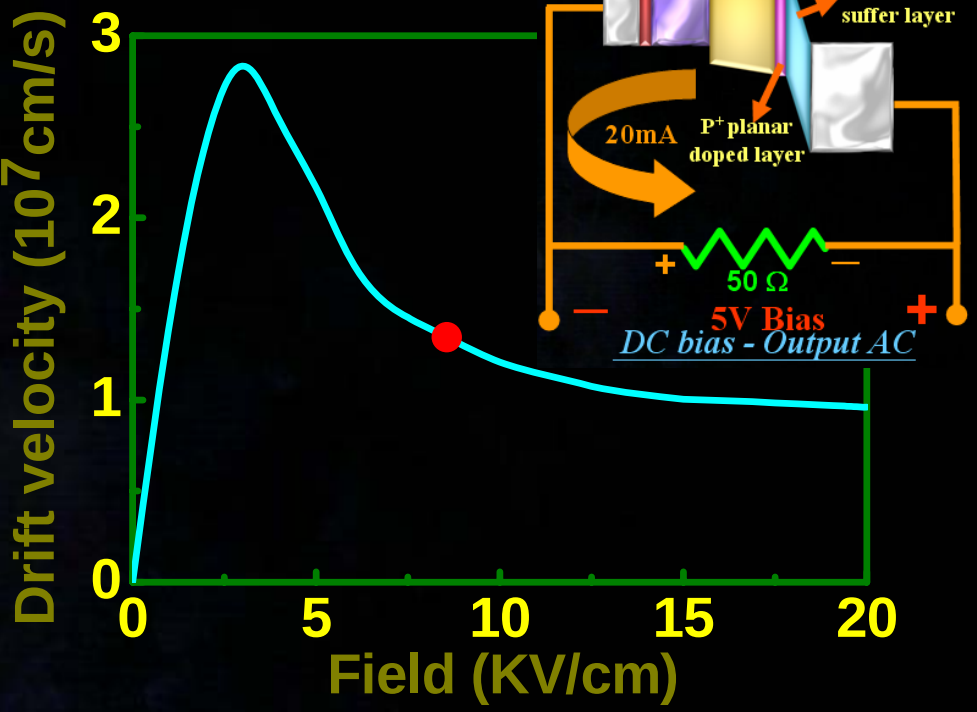
With the Same Trends !!

RC Effect: Reduction of AC Capacitance

The reduction of AC capacitance can be observed from the S22 parameter under high photocurrent generation.

Capacitance= $I_C X(^{d\tau_C}/_{dV_{ac}})$





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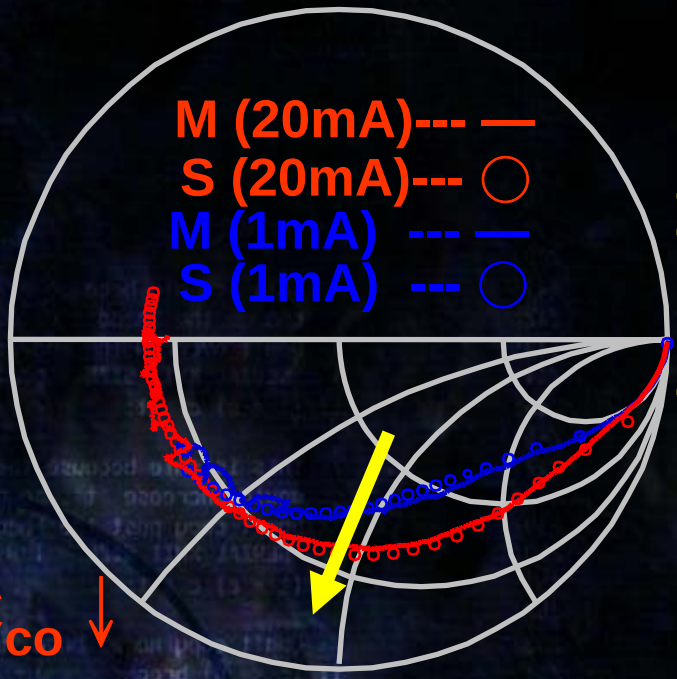
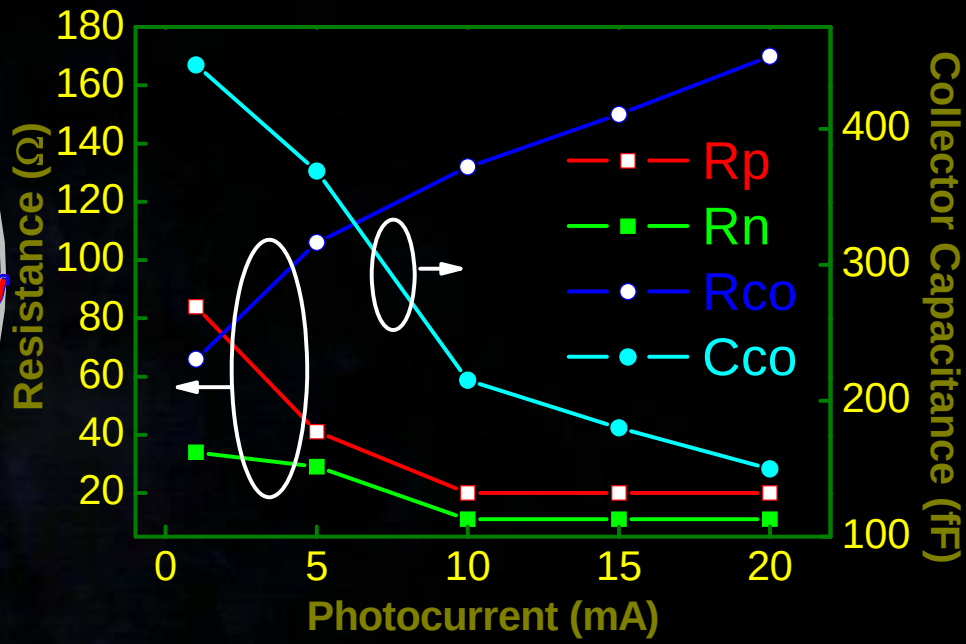
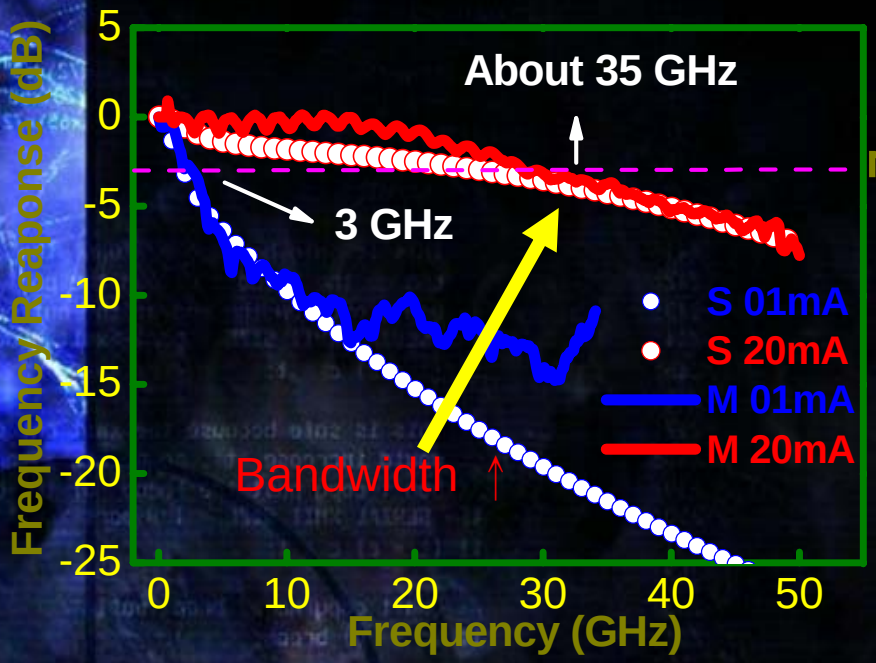
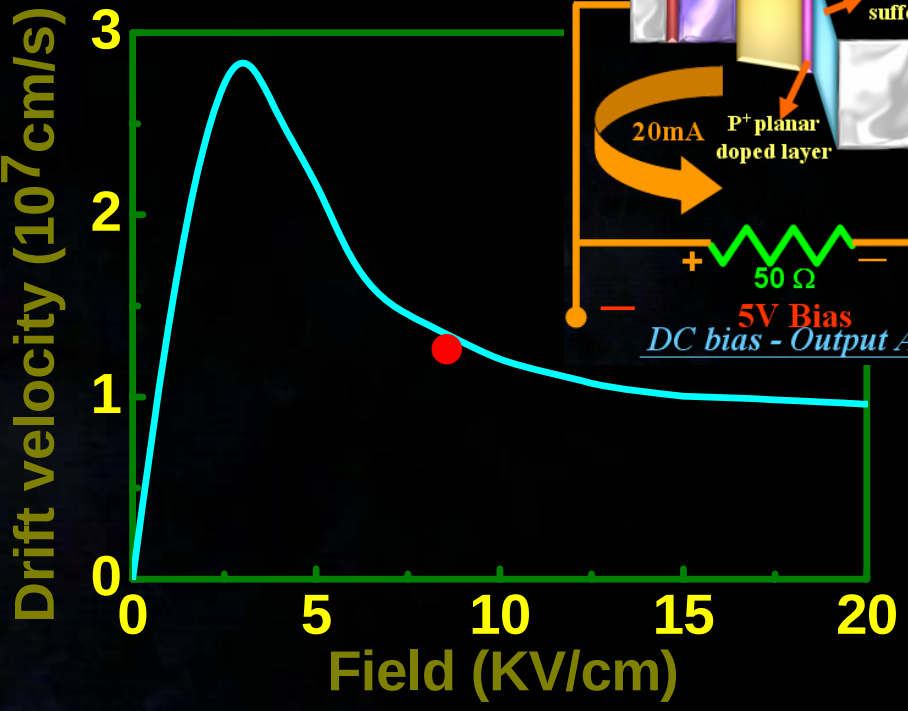




Carrier-Transport-Effect: Electron Velocity Overshoot

The Near-Ballistic transport can be observed when NBUTC-PD operated under -5V bias voltage, and 20mA photocurrent generation.





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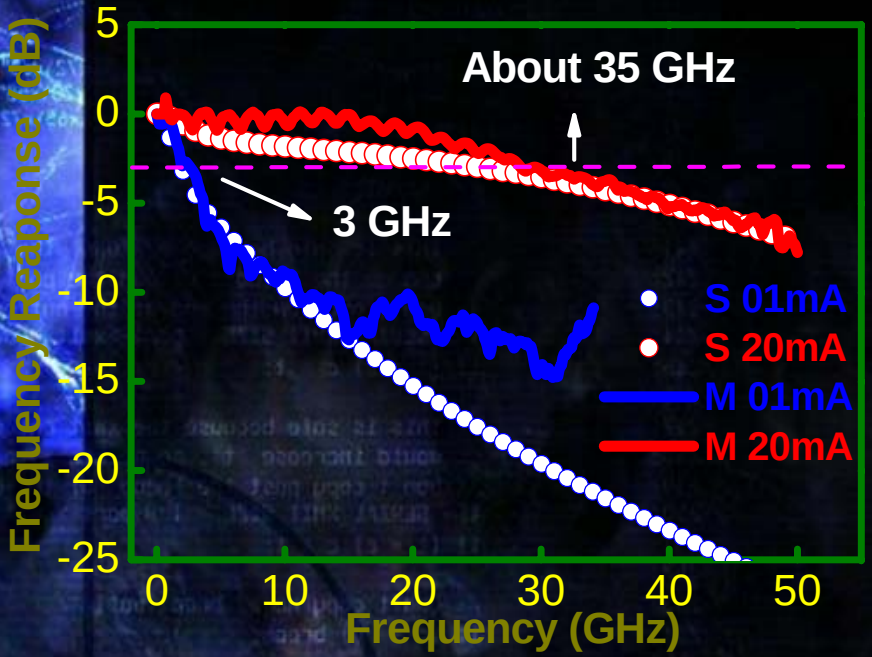
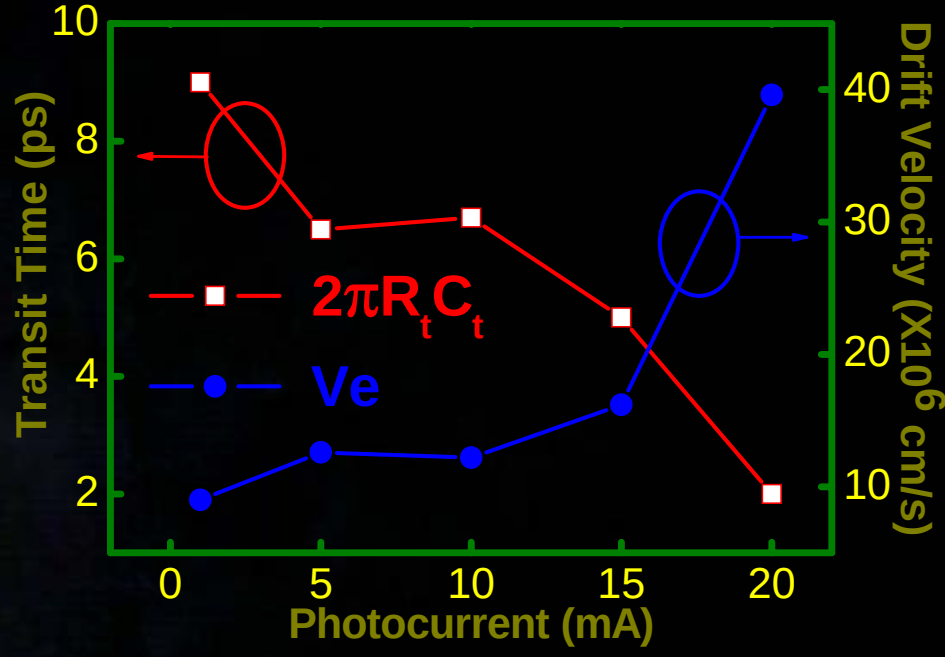
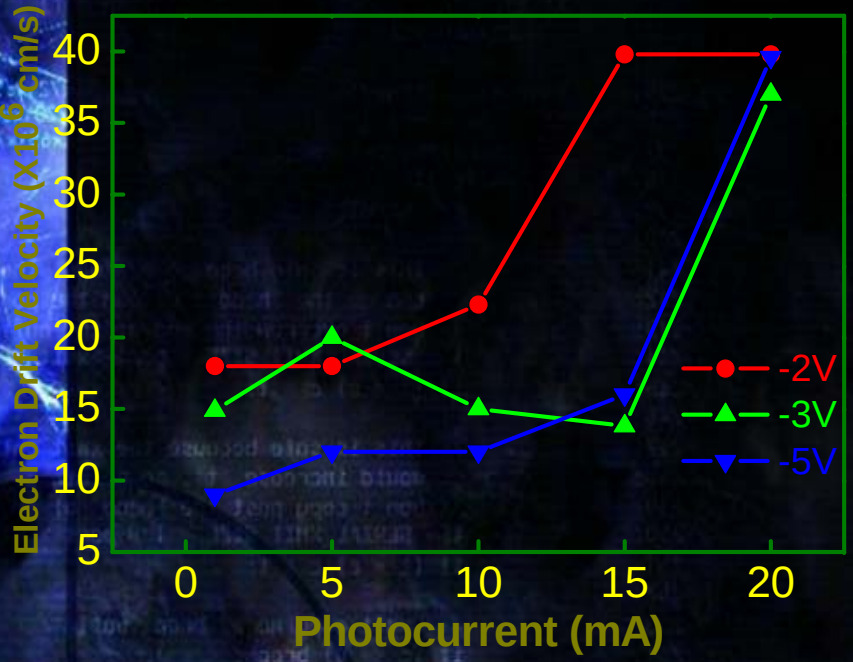
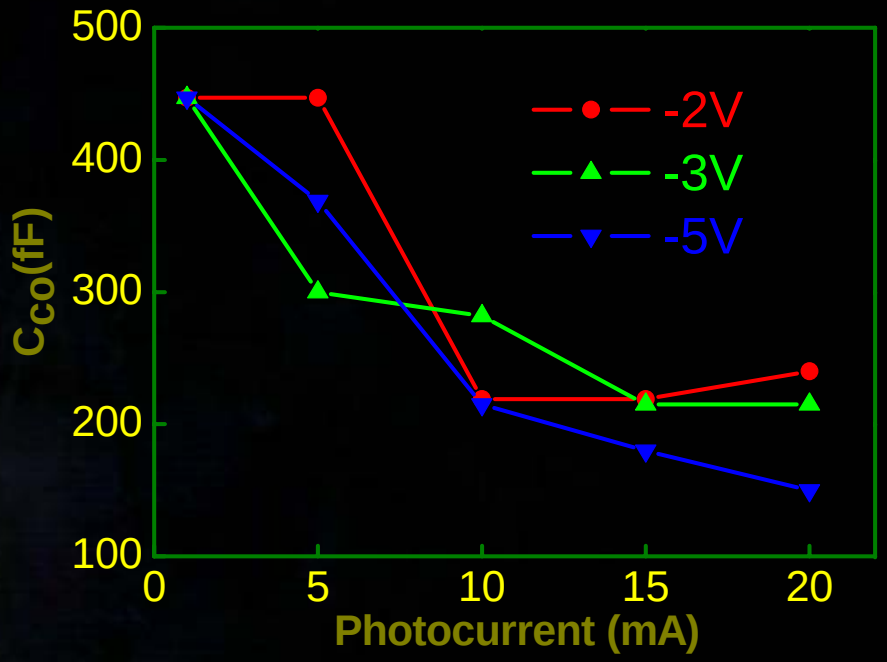




Bias & Current-Dependent Equivalent Circuit Model

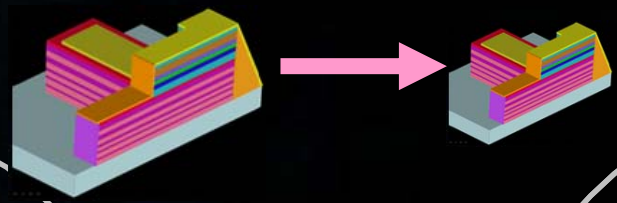
The reduction of capacitance usually accompanies the occurrence of near-ballistic transport when the photo-generated current is lager then 10mA.





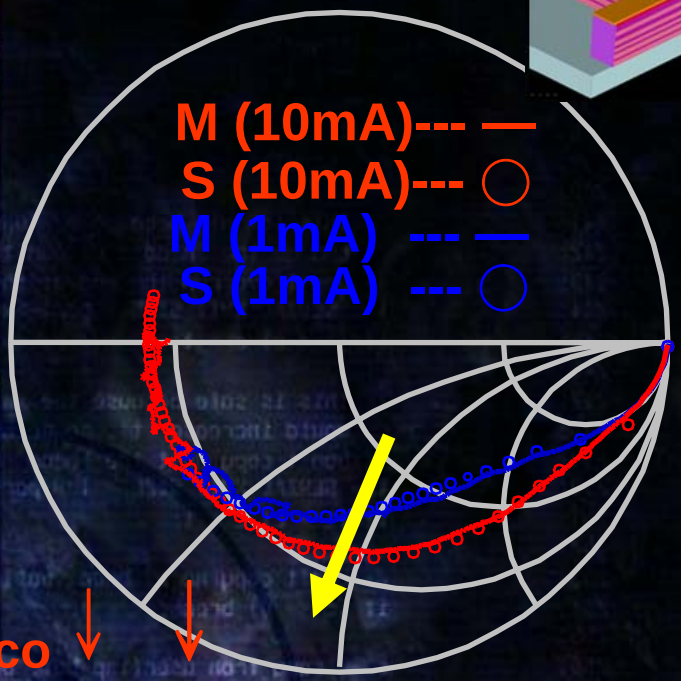
The Bandwidth Enhancement Not Obvious at Small Size !?

The reduction of AC capacitance not only dependent on the slope of drift velocity versus electric field, but also the area of active region.



320 μm²

M (10mA)--- —
S (10mA)--- ○
M (1mA) --- —
S (1mA) --- ○

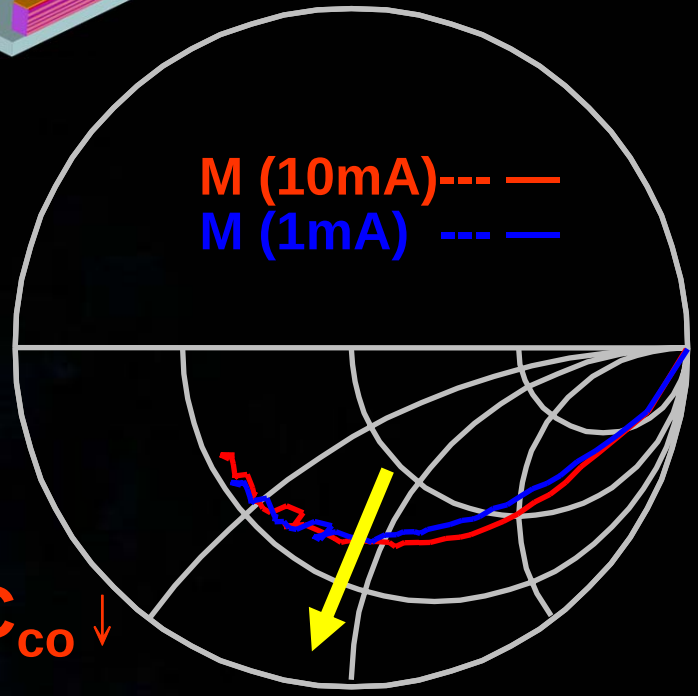


C_{co} ↓

Frequency (DC to 50.00GHz)

132 μm²

M (10mA)--- —
M (1mA) --- —



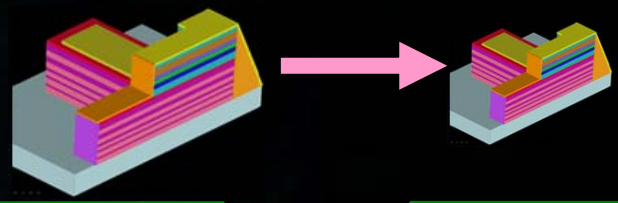
C_{co} ↓

Frequency (DC to 50.00GHz)

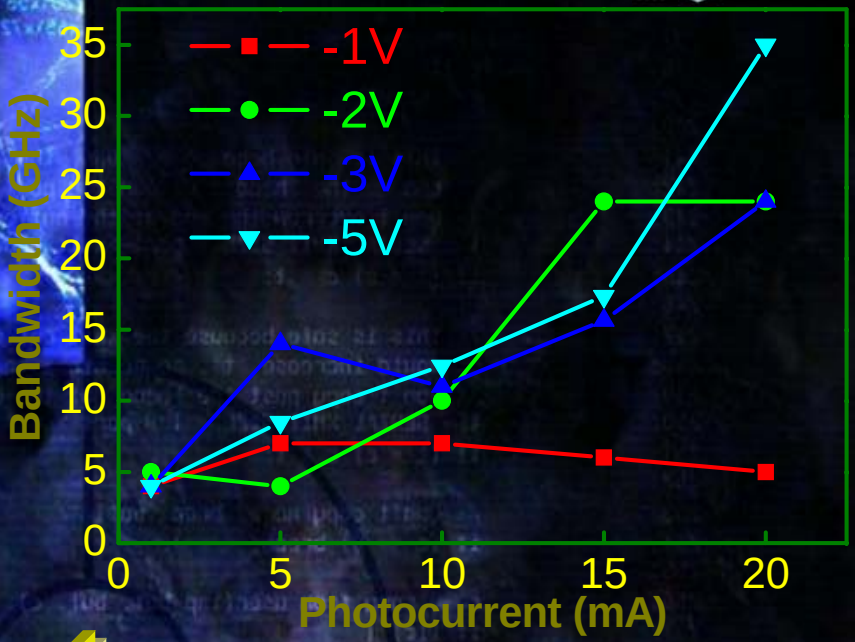
The Bandwidth Enhancement Not Obvious at Small Size !?

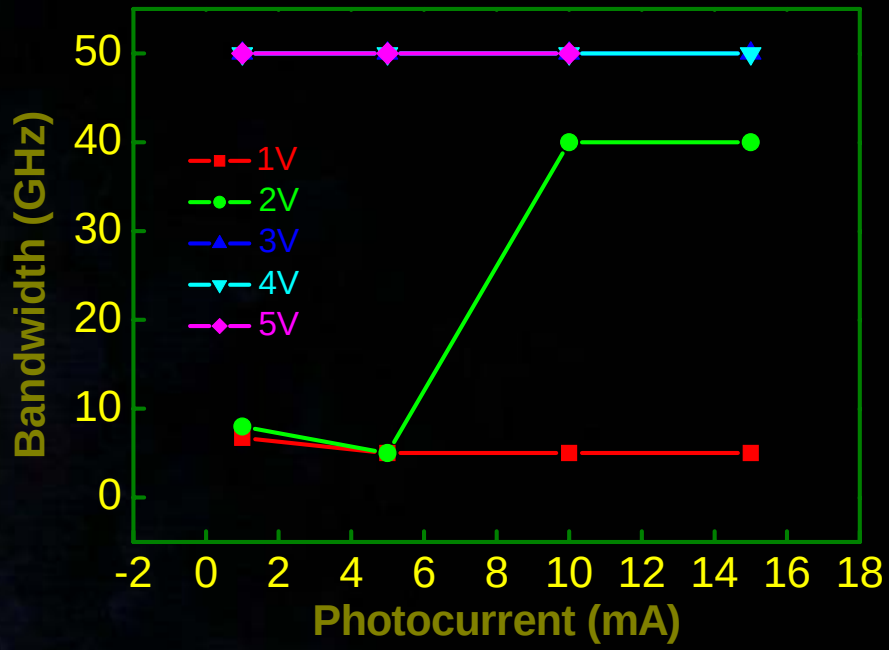
The limitation of measured bandwidth of small size BUTC-PD is thermal issue & Modulator Bandwidth!!

320 μm²



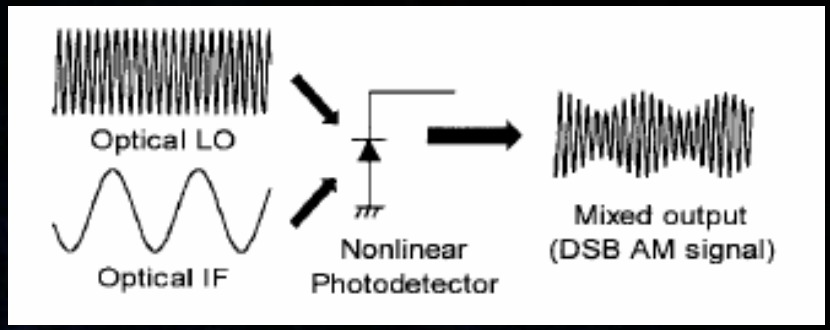
132 μm²

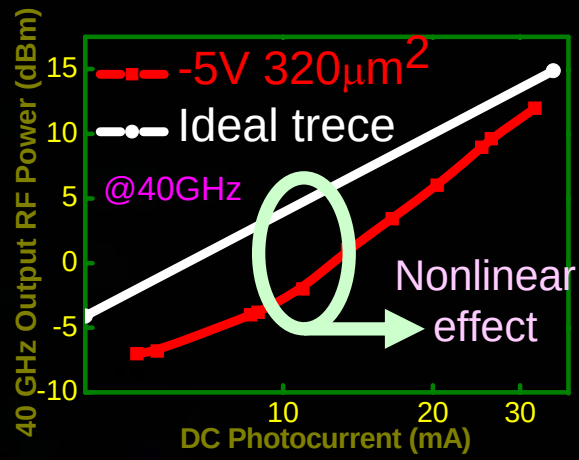




Applications

Large Size device:

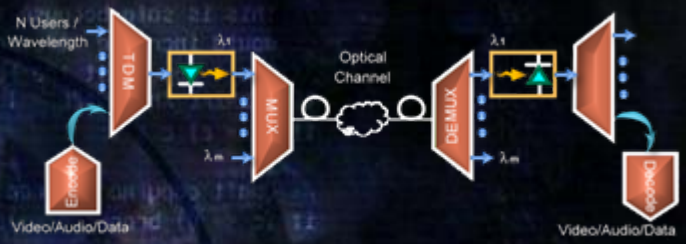




Can apply to optoelectronic mixer

Operate at nonlinear region still with high speed

Small Size device:



Benefit to analog optical fiber communication system

I. Motivation

II. The Structure of BUT-CPD

III. Measurement System

IV. Model Extraction

V. The Fitting Results

VI. Conclusions

Conclusions

- we have analyzed the dynamic behaviors of NBUTC-PD under different output photocurrent and bias voltage by use of light-wave-component (LCA) analyzer. By utilizing the extracted scattering parameters and equivalent-circuit-model fitting, the unique bandwidth enhancement can be attributed to the ac capacitance reduction and near-ballistic transport of electron under high output photocurrent.

Thanks for Your Attention !!!