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# 1/f noise study as a non-destructive test to check MOSFET

P. Ananda[1], S.Victor Vedanayakam[2], K.Thyagarajan[3] N. Vijaya Lakshmi[4]
[1]*Research Scholar, JNTUA Anantapuramu & MITS Madanapalle, A.P. India.*
[2]*Dept. of Physics, Madanapalle Institute of Technology and Science, Madanapalle, A.P. India*
[3]*Dept. of Physics, JNTUCEP, Pulivendula, A.P. India*
[4]*Dept. of Physics, Nehru Memorial Govt. Degree College, Jogipet, T.N. India*

***Abstract :*** *1/f noise studies play significant role in choosing the band of frequency in which a device can be commendably used. This property is used to check the MOSFET without disturbing its physical structure. A MOSFET is used for intensifying or swapping electronic signals since it is a semiconductor gadget and also helps the electronic devices to run at a high capacity than they would otherwise. This particular device allows for parallel currents to distribute their power. In the present paper1/f noise and nonlinear effects in MOSFETs IRF 340, IRF 440 and IRF 640 are studied. The MOSFETs IRF 440 and IRF 640 show quite a large deviation compared to 1/f line in the lower frequency region while IRF 340 1/f nature matches it at low frequency.*
***Keywords:*** *1/f noise, band of frequency, Current densities, γ value, MOSFET etc.*

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## I. Introduction

MOSFET have major advantage over the conventional JFET or FET. The gate terminal has the electrical insulation from the channel allows to block the current flow from the channel to gate terminal with irrespective of gate voltage. In practical, the Mosfet has the infinite impedance and utilized for the power amplifier in the electronic circuits. Due to the high-speed stitching and super junctions, MOSFETS are used in many computers [1].

The switching time of MOSFET affected by its junction capacity. Under the MOSFET working condition in the reverse bias the drain PN junction is weak due to the low current flow. On the other hand the channel and the gate are insulated, the gate has very low current and noise is ignored. The Mosfet has thermal noise or 1/f noise and audible range of frequency. The gate voltage controls the 1/f noise of its own terminal in the MOSFET [2]. The switching speed of MOSFET is affected by the 1/f noise.

In MOSFET the channel depth is always proportional to the gate voltage and as soon as the gate voltage is removed its pinches are closed, so there is no storage time effect in them as occurs in transistors. A MOSFET when used as a switch, it functions to control the current in single phase to three phase inverter. When used for amplification, it functions to amplify DC signals [3].

Minute entities of fluctuations are because of source of 1/f noise and are used for measuring microscopic values on a scale. A band spectrum of 1/f noise is excess or flicker noise [4]. The modern radio physics problems can be solved using description of 1/f like spectrum. This 1/f noise restricts stability and sensitivity of electronic radio device. To reduce 1/f noise, the requirements are increasing. In atom level processes the 1/f noise fluctuations can be noticed. The MOSFET manufacturing materials and processes evaluation bears the 1/f noise constraint when used in solid micro-structure state and also in semiconductor ICs [5]. The electro migration immunity can be processed in metallization of thin film ICs. By latest measuring instrumentation constructed for the studies, theoretical and practical results are matching [6-7].

## II. Models for 1/f noise and their experimental basis

The 1/f noise phenomenon was explained by many models proposed by researchers, but each one has its own merits and setbacks. There is no common agreement among scientific community regarding "whether all observed 1/f noise mechanisms have certain common basis or whether there exists a common mathematical basis that explains all 1/f noise phenomena" [8]. There is a strong feeling amongst the various research groups engaged in noise research that there may exist more than one or more mechanism contributing to observed 1/f noise. This conclusion requires different theories to explain all the experimental facts pertaining to 1/f noise [9].

### II.1 Hooge's hypothesis

In 1969, Hooge established a phenomenological relationship for resistance Fluctuations

$S_i / I^2 = S_R / R^2 = \alpha / N_{tot} f$ (1)

$S_i$ power spectral density of current fluctuations,

$S_R$ is the power spectral density of the resistance fluctuations both being frequency dependent function,

I and R are the mean current and mean resistance respectively,

$N_{tot}$ is the total number of charge carriers in the specimen,

f is the frequency and α is a constant that is only a slowly varying function of the temperature T

and α is called as Hooge's constant and has a value of about $2x10^{-3}$.

According to Hooge, 1/f noise stems from resistance fluctuations in a manner shown by Eq. (1) [10-11]. The original claim of Hooge that Eq. (1) applies to all homogeneous materials received setbacks from the studies of Dutta et al and Eberhard and Horn. Later on, Hooge and Vandamme invoked a correction to Eq. (1). Vander Ziel has done excellent study of 1/f noise in electronic devices in terms of the Hooge's parameter. Vander Ziel's experimental results have been compared with Handel's predictions for which have been proved Handel's predictions to be correct.

### II.2 Approach of Voss and Clarke

The thermal fluctuation model, developed by Voss and Clarke suggested that, resistance fluctuations are caused by equilibrium thermal fluctuations [12]. According to the statistical mechanics of the equilibrium state for a canonical ensemble, the average of the energy fluctuations E of a system in contact with a heat bath is given by,

$(\delta E)^2 = kT^2/Cv$ (2)

where k, T and Cv are the Boltzmann constant, temperature and the heat capacity of the system. Since energy fluctuations are connected with temperature fluctuations through $\delta E = C_V \delta T$, it is obtained that,

$(\delta T)^2 = kT^2 / Cv$ (3)

The model of Voss and Clarke is a model for spontaneous, equilibrium enthalpy fluctuations. Treating the temperature of the sample as a fluctuating quantity is an intuitive concept. We choose to retain the concept of Voss and Clarke [13, 14]. Temperature fluctuations lead to resistance fluctuations through dR/dT which is called the temperature coefficient of resistance of the sample. The mean square resistance fluctuations are given by,

$(\delta R)^2 = (dR/dT)^2 (\delta T)^2$ (4)

Defining $\beta = R^{-1} (dR/dT)$

$(\delta R)^2 = \beta^2 R^2 kT^2 / Cv$ (5)

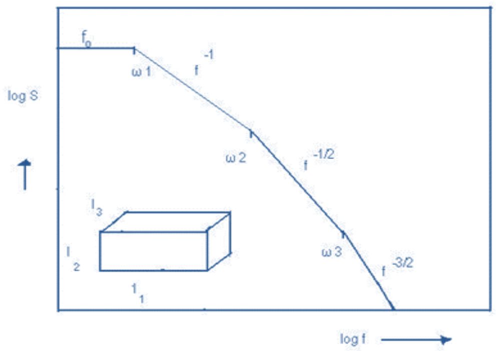
Energy being a conserved quantity, the frequency spectrum of the above model can be given by the standard diffusion equation approach. Voss and Clarke have used the Langevin diffusion equation

$\delta T / \delta t = D^2 T + C^{-1}$ (6)

where, D is the thermal diffusivity,

C is the specific heat and F is an uncorrelated random driving term.

Noise spectrum derived from diffusion equation in sample of dimensions $I_1$ x $I_2$ x $I_3$; and three regions are clearly demarked



## III 1/f Noise and non-linear studies in MOSFETs

In MOSFET it would be quite stimulating to check the linearity of γ as a function of current density. The observed values of –γ are plotted as a function of current density in different figures. The power γ tends to increase as current density is increased. The –γ values are seeming to approach the hypothetical value of unity for lower currents as visualized in literature [15-16].

Each device record in the form of digital data is obtained for selected biased condition. Plotting directly the quantitative measurements [17] and magnitudes is not distinguishable. Thus Power Spectral Density from MATLAB Software is used as records of digital data. Unique noise signs of Device under Test (DUT) are available from FFT records. This digital data from the observations of MATLAB [18-19] analysis have important information of DUT. The plots of raw noise records of present study are shown below. These are of noise of individual devices.

The Fig.1 represents noise patterns similar in 8-bit pulse code amplitude for IRF 640 for different drain voltages. The FFT transform of the noise input is the simplest way of translating the noise data into spectral power density form. The noise patterns shown in Fig. 2 represent the variation of the frequency with magnitude of FFT for different current densities.

The MOSFETs IRF 640, IRF 440 and IRF 340 are studied in the present work. Power spectral density, in the form of averaged magnitude of FFT, is plotted as a function of frequency. Fig.3.1 and 3.2 are the plots for IRF 640 for six values of drain voltages at constant gate voltage. The theoretical estimates predict γ = -0.496, while the observed average values of –γ are tabulated in Table 1 Fig.3.3 and 3.4 are the plots for IRF 440 for six values of drain volt ages at constant gate voltage. The theoretical estimates predict γ = -0.489, while the observed average values of –γ are tabulated in Table 2 Fig.3.5 and 3.6 are the plots for IRF 540 for six values of drain voltages at constant gate voltage. The theoretical estimates predict γ = -0.438, while the observed average values of –γ are tabulated in Table 3.

The MOSFETs IRF 640 and IRF 440 Show quite a large deviation compared to 1/f line in the lower frequency region while IRF 340 at low frequencies show 1/f nature. A careful observation of 1/f studies in them indicates co-existence of multiple mechanisms. It is necessary to appropriately identify the mechanisms either on basis of theory or on the experimental.

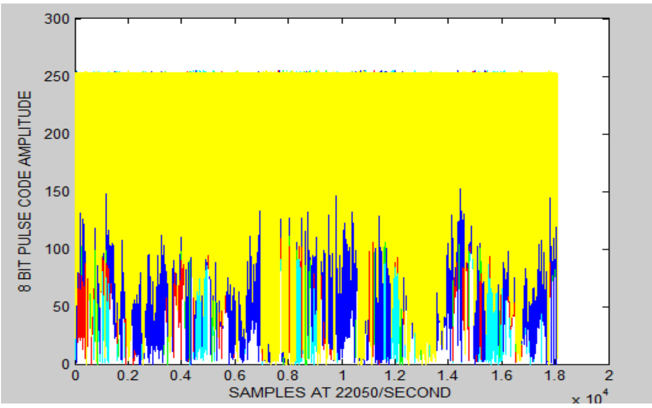



Fig.1 Different Drain Voltages, 8-Bit Pulse Amplitude of IRF 640.

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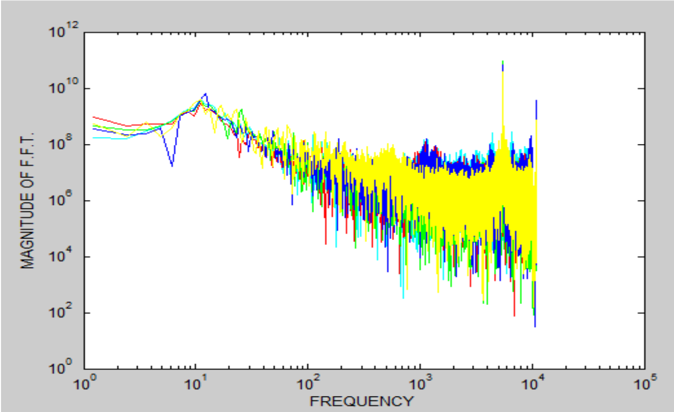


Fig. 2 FFT Amplitude of IRF 640 for Different Drain Voltages

Fig 3.1 for Different Drain Voltages at $V_g$ = 3.60V the 1/f Noise in the MOSFET IRF 640
[$V_d$ = 0.10V, 0.12V, 0.14V, 0.16V, 0.18V, 0.20V]

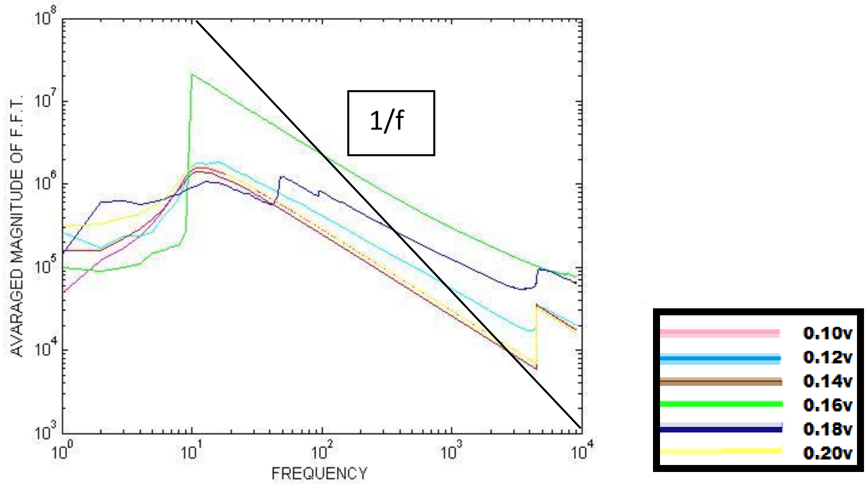


Fig 3.2 for Different Drain Voltages at $V_g$ = 3.92V 1/f Noise in the MOSFET IRF 640
[ $V_d$ = 0.10V, 0.12V, 0.14V, 0.16V, 0.18V, 0.20V]

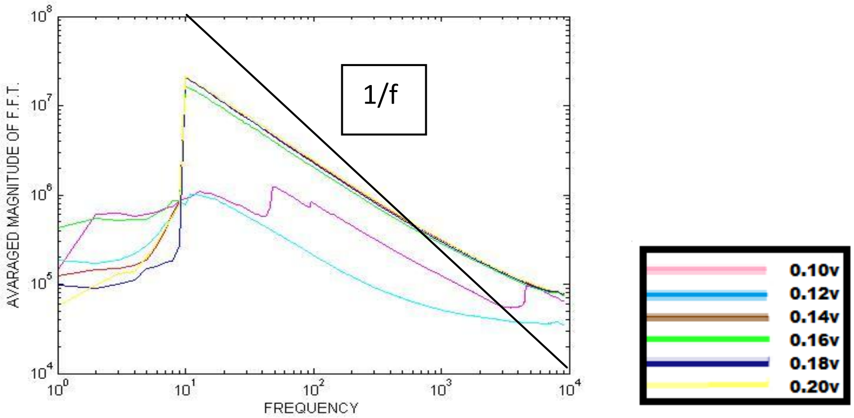


Fig 3.3 for Different Drain Voltages at $V_g$ = 3.50V 1/f Noise in the MOSFET IRF 440
[$V_d$ = 0.10V, 0.12V, 0.14V, 0.16V, 0.18V, 0.20V]

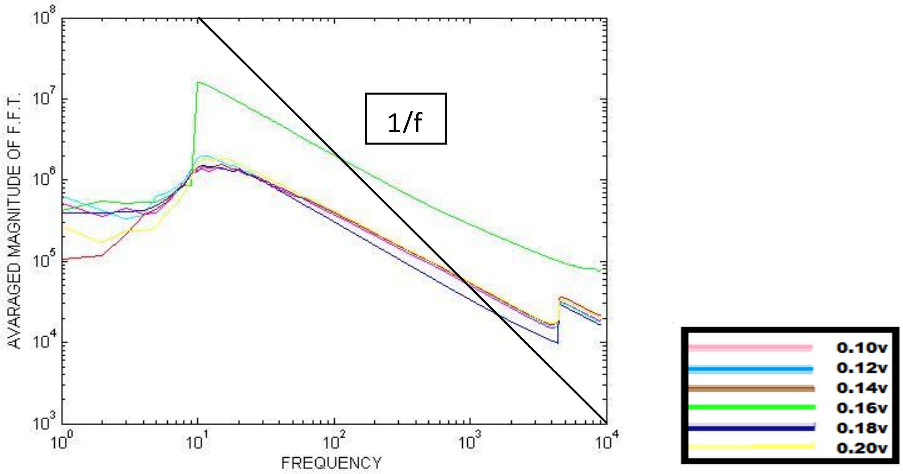


Fig 3.4 for Different Drain Voltages at $V_g$ = 3.95V1/f Noise in the MOSFET IRF 440
[ $V_d$ = 0.10V, 0.12V, 0.14V, 0.16V, 0.18V, 0.20V]

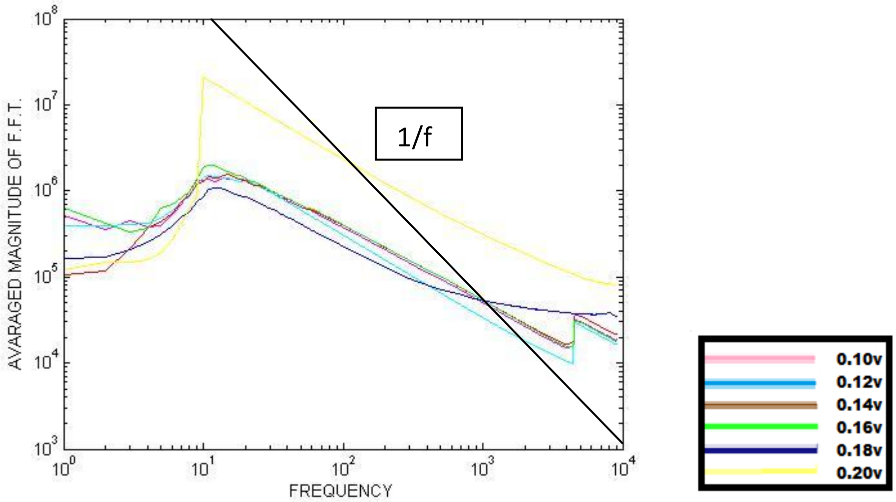


Fig 3.5 for Different Drain Voltages at $V_g$ = 3.25V 1/f Noise in the MOSFET IRF 340
[ $V_d$ = 0.10V, 0.12V, 0.14V, 0.16V, 0.18V, 0.20V]

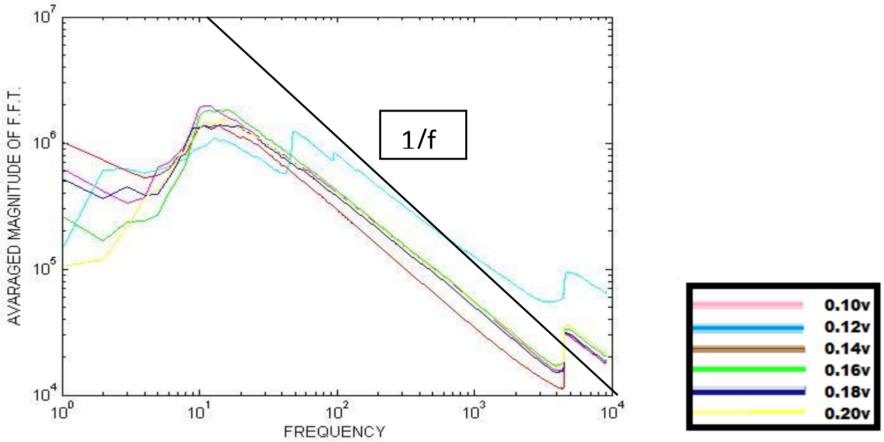


Fig 3.6 for Different Drain Voltages at $V_g$ = 3.65V 1/f Noise in the MOSFET IRF 340
[ $V_d$ = 0.10V, 0.12V, 0.14V, 0.16V, 0.18V, 0.20V]

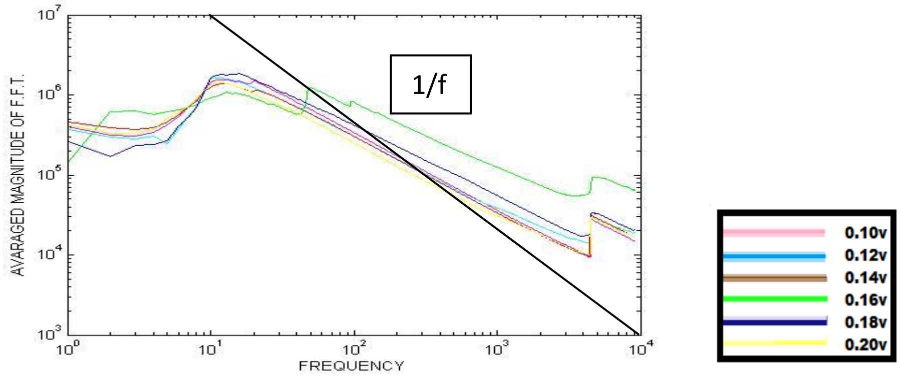


Table.1 for IRF 640 at $V_g$=3.60V and 3.92V the Average slopes of 1/f graphs

| S.No | $V_g$ | $V_d$ | Color of Graph | Average Slope Γ |
|---|---|---|---|---|
| 1 | 3.60V | 0.10V | Magenta | -0.501 |
| | | 0.12V | Cyan | -0.482 |
| | | 0.14V | Red | -0.425 |
| | | 0.16V | Green | -0.473 |
| | | 0.18V | Blue | -0.584 |
| | | 0.20V | Yellow | -0.452 |
| 2 | 3.92V | 0.10V | Magenta | -0.523 |
| | | 0.12V | Cyan | -0.583 |
| | | 0.14V | Red | -0.482 |
| | | 0.16V | Green | -0.480 |
| | | 0.18V | Blue | -0.485 |
| | | 0.20V | Yellow | -0.483 |

Table 2 for IRF 440 at Vg=3.50V and 3.95V the Average slopes of 1/f graphs.

| S.No | $V_g$ | $V_d$ | Color of Graph | Average Slope Γ |
|---|---|---|---|---|
| 1 | 3.50V | 0.10V | Magenta | -0.519 |
| | | 0.12V | Cyan | -0.461 |
| | | 0.14V | Red | -0.442 |
| | | 0.16V | Green | -0.485 |
| | | 0.18V | Blue | -0.509 |
| | | 0.20V | Yellow | -0.443 |
| 2 | 3.95V | 0.10V | Magenta | -0.521 |
| | | 0.12V | Cyan | -0.532 |
| | | 0.14V | Red | -0.519 |
| | | 0.16V | Green | -0.484 |
| | | 0.18V | Blue | -0.491 |
| | | 0.20V | Yellow | -0.484 |

Table .3 for IRF 340 at $V_g$=3.25V and 3.65V the Average slopes of 1/f graphs

| S.No | $V_g$ | $V_d$ | Color of Graph | Average Slope Γ |
|---|---|---|---|---|
| 1 | 3.25V | 0.10V | Magenta | -0.420 |
| | | 0.12V | Cyan | -0.461 |
| | | 0.14V | Red | -0.442 |
| | | 0.16V | Green | -0.485 |
| | | 0.18V | Blue | -0.409 |
| | | 0.20V | Yellow | -0.443 |
| 2 | 3.65V | 0.10v | Magenta | -0.423 |
| | | 0.12V | Cyan | -0.442 |
| | | 0.14V | Red | -0.419 |
| | | 0.16V | Green | -0.445 |
| | | 0.18V | Blue | -0.432 |
| | | 0.20V | Yellow | -0.454 |

## IV Results

The present study results on 1/f noise of semiconductor devices are discussed. The plots represent the noise recorded for one individual device. 1/f noise studies have been investigated for the MOSFETs and their dependence on the gate voltage at different drain voltages is studied. The average power spectral density is inversely proportional to drain voltage while it is directly proportional to $f^{-\gamma}$.

The MOSFETs IRF 440 and IRF 640 show quite a large deviation compared to 1/f line in the lower frequency region while IRF 340 1/f nature matches it at low frequency. Increase of current in MOSFETs leads to the increase of the carries in the surface channel region and hence an increase in 1/f noise.

In the case of IRF 640, $\gamma$ values that are the average slope recorded in the present work ranges from -0.486 to -0.506, a deviation appears at 0.18V for a gate voltage of 3.60V and also 3.92V. In IRF 440 $\gamma$ values recorded from -0.476 to -0.503 and increase is observed at 0.18V for gate voltage of 3.50V and 3.95V. In the case of IRF 340, $\gamma$ values recorded from -0.443 to -0.439, a steady decrease is observed.

## V Conclusions

From this study 1/f noise study is regarded as a non-destructive test to check MOSFETs. In MOSFETs the 1/f noise is found to be due to leakage of minority carriers in the drain interface or junction region. Increase of current in MOSFETs leads to increase of the carriers in the surface channel region and hence an increase in 1/f noise.

The contribution to 1/f noise can be determined by a careful study on MOSFETs and it increases with increase in drain voltage and decreases with increasing gate voltage. But in IRF 640 and IRF 440 it shows an increase at certain drain voltage representing a deviation from its linear effect, hence 1/f noise promises to be an early indicator of damage. The noise power which has to be proportional to square of the noise voltage, $V^2$ (or $I^2R^2$) under equilibrium condition, actually found proportional to $V^{2+\gamma}$ where $\gamma>0$. . The results are comparable with the existing literature in this area. Small current densities would tend to normal 1/f behavior and additional currents would result in to pouncing current conduction increasing the value of the slope $\gamma$

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