An Orthogonal Decoupling Method of Co-frequency Antennas for Smart Watch Applications

Rui Lv[1] and peiyu liu[2]

[1]Shenzhen Institute of Information Technology
[2]Shenzhen Polytechnic

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Abstract

This letter proposes an orthogonal decoupling method for co-frequency MIMO antennas with unbroken metal rim, operating in Wi-Fi 2.4GHz. The decoupling technique just requires two lumped elements between two ports.Two orthogonal surface currents and radiation pattern diversity are obtained. By adding a capacitive and an inductor, with insensitive of matching circuits, it is easy and significant to improve isolation with near 50dB for smart watch antennas. Moreover, forearm causes lower isolated frequency, and has a little effect on impedance matching with the radiation pattern orthogonal to the forearm.

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Rui Lv,[1] ,Peiyu Liu[2]

1 Shenzhen Institute of Information Technology, Shenzhen, China

2 Shenzhen Polytechnic, Shenzhen, China

Email: lvrui@sziit.edu.cn

This letter proposes an orthogonal decoupling method for co-frequency MIMO antennas with unbroken metal rim, operating in Wi-Fi 2.4GHz. The decoupling technique just requires two lumped elements between two ports. Two orthogonal surface currents and radiation pattern diversity are obtained. By adding a capacitive and an inductor, with insensitive of matching circuits, it is easy and significant to improve isolation with near 50dB for smart watch antennas. Moreover, forearm causes lower isolated frequency, and has a little effect on impedance matching with the radiation pattern orthogonal to the forearm.

Introduction: Smart watches become an important component of the Internet of Things (IoT). Many wireless techniques are applied to user scenarios, such as LTE cellular communications, Wi-Fi, near field communication (NFC), or ultrawide band (UWB). At present, 2.4-GHz wireless local-area network (WLAN), Bluetooth and GPS are the most common wireless communication protocols adopted in commercially available smartwatch products [1]. However, there are many challenges in designing multiple and multiband antennas on smart watches. Firstly, severe mutual coupling of antennas with unbroken metal rim lowers total efficiency and deteriorates channel capacity. For example, Wi-Fi 2.4GHz and LTE B40(2300MHz-2400MHz) have strong coupling, often operating in different antennas because of more than 2dB insertion loss of extractors. Forearm also has important effects on isolations and efficiency degradation. A limited space and industry design have no chance to use bulk decoupling methods, such as neutralization line or special ground structure [2,3,4]. Secondly, curved full display and other components decrease the clearance, or no ground region, to reduce system efficiency. Thirdly, mixed higher order modes inevitably introduce surface current cancellation and more nulls in the radiation patterns [5].

This article discusses a simple and effective decoupling method for two Wi-Fi 2.4GHz MIMO antennas. The technique introduces two orthogonal modes with 90-degree rotation of surface current and radiation pattern by adding two lumped components. The loadings are insensitive to antenna matching network and their values are determined by isolated frequency and their placements. Also, forearm effect on the isolation is demonstrated with GaN back cover.

Decoupling Formula: Network of four ports can be expressed by its impendence matrix. In Fig.1, Port1 and Port2 mean the feed ports of Antenna1 and Antenna2, respectively. Port3 and Port4 are respectively the decoupling loads, $Z_{L1}$and Z_{L2}.Substituting$Z_{L1}I_3 = V_3, Z_{L2}I_4 = V_4$ to the impendence matrix, a quadratic equation of unknown $Z_{L1}$and Z_{L2} results in two possible solutions [6]:

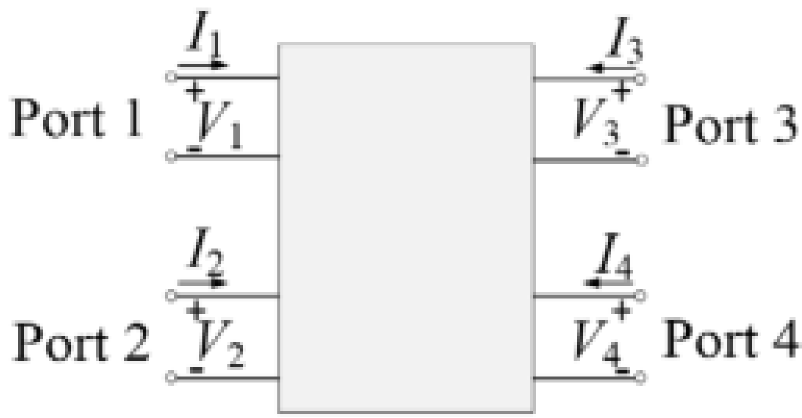


Fig. 1 *Four-port network*

Design Process: The equations above will become more complicated to be solved as the number of load ports increases. So, a parameter sweep method is presented to find these solutions quickly, easy to apply in engineering. A simple metal housing with a clearance 1mm (06) is a size of 42mm*38mm as an example in Fig.2. Cp (04) and Lp (03) connected to PCB ground (05) are lumped elements to decouple of Port1(01) and Port2(02), operating in the WiFi-2.4G. The material of metal rim and PCB is copper.

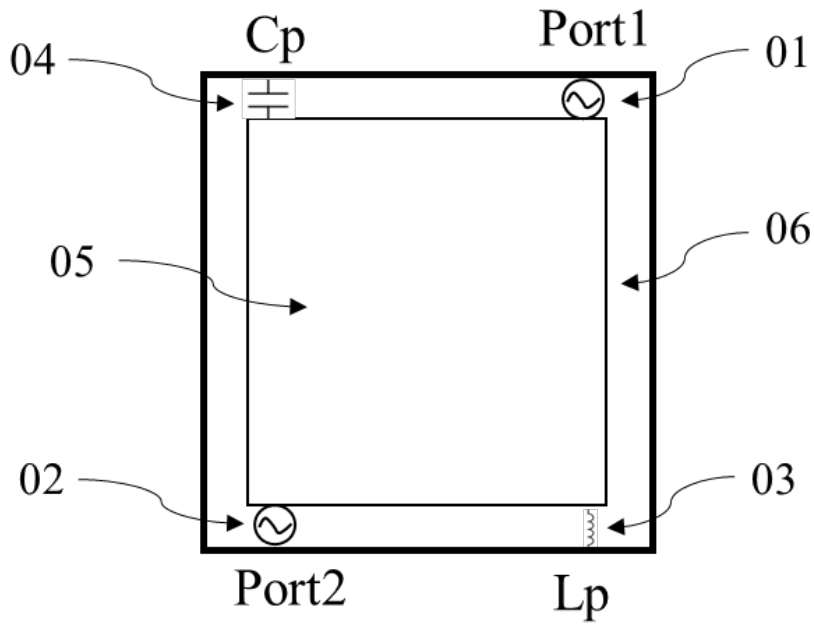
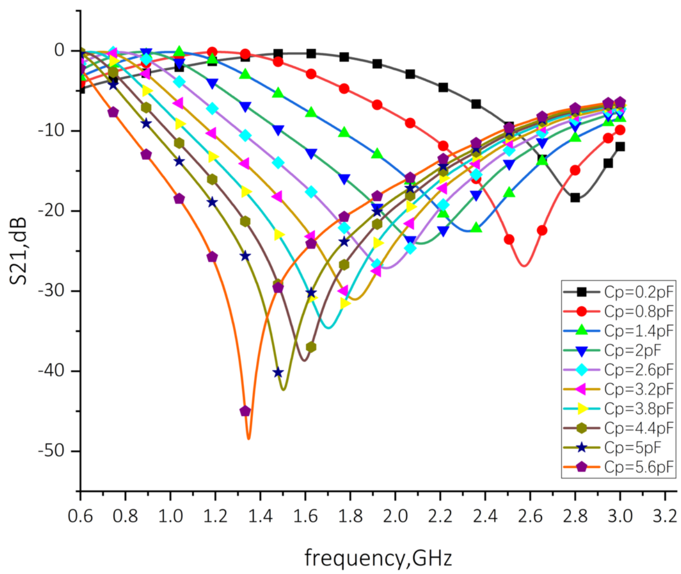
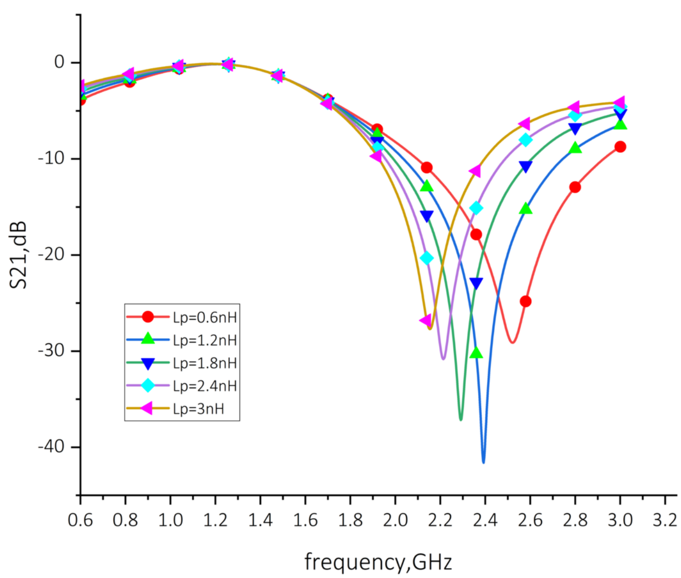


Fig. 2 *A simple metal rim model*

Matching circuits of separate feeding ports can just change its amplitude or curve depth of S21 and have a little effect on S21 notch frequency. So, we can sweep parameters Cp and Lp to obtain a good isolation without matching circuits. Simulations are done by applying CST Studio Suit 2022, a full wave simulation software. Firstly, Lp is fixed to 1nH, and Cp increases from 0.2pF to 6.2pF, with empty matching circuits of Port1 and Port2. Secondly, Cp is fixed to 0.8pF, and Lp increases from 0.6nH to 3nH. Fig.3 shows S21 notch frequency decreases with the increasement of Cp and Lp. Low bands have a large range and broad bandwidth with Cp while Lp mainly influences on high bands. A combination of Cp=0.7pF, Lp=1.6nH consists of well decoupled elements.



(a)

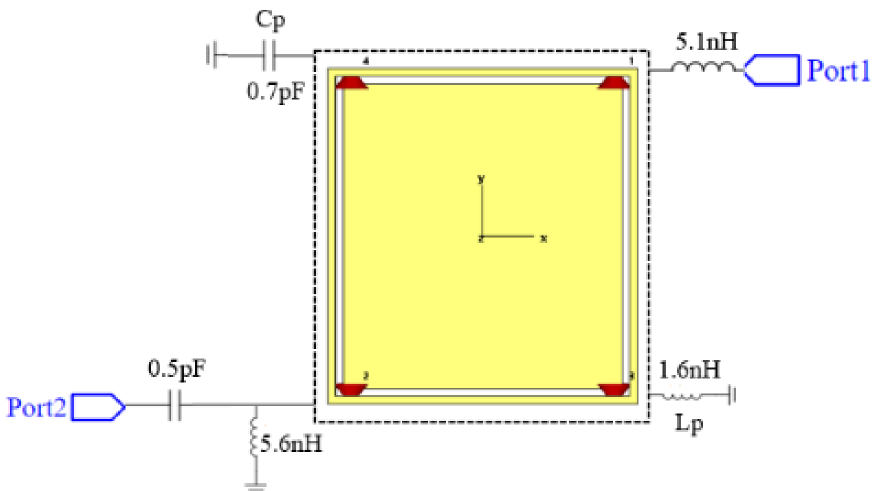


(b)

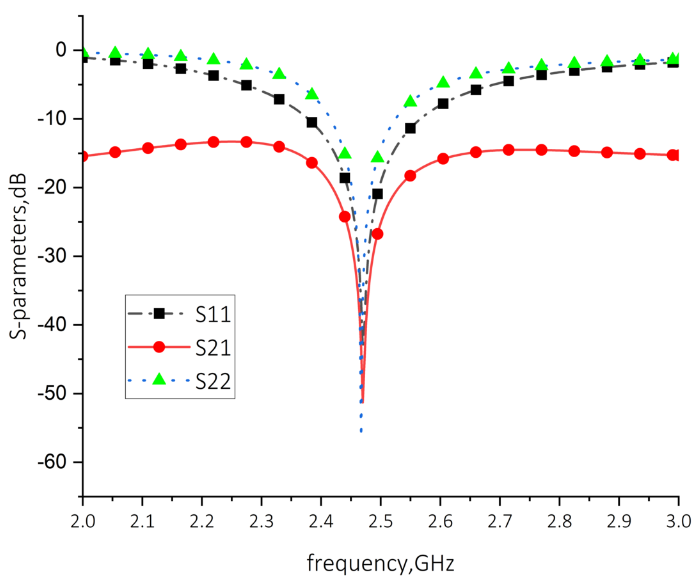
Fig. 3 *parameter sweep of Cp and Lp. (a) S21 with a variation of Cp.(b) S21 with a variation of Lp.*

Adding matching circuits for each port, a very good isolation with 50dB, and good system efficiency near

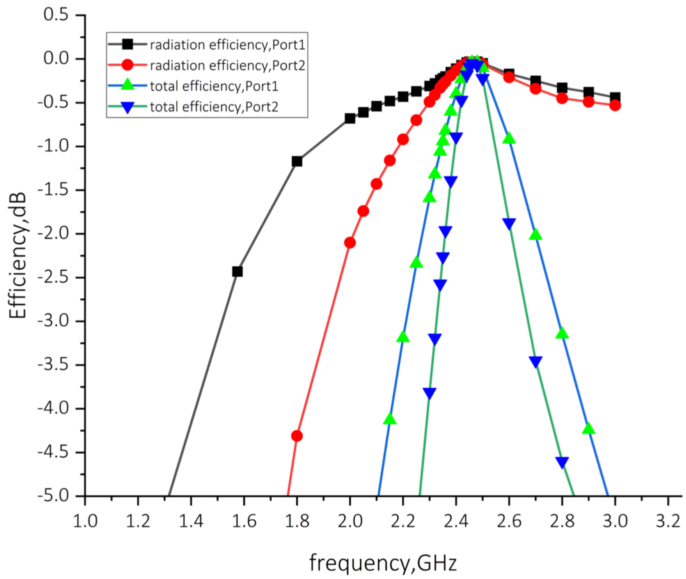
100% are achieved in Fig.4. Fig.5 shows that the common mode is excited in the x-axis of Port1, and differential mode is excited in the y-axis of Port2. In the 90-degree rotation, the differential mode is excited in the x-axis of Port1, and common mode is excited in the y-axis of Port2. There is a characteristic of orthogonal radiation patterns.



(a)

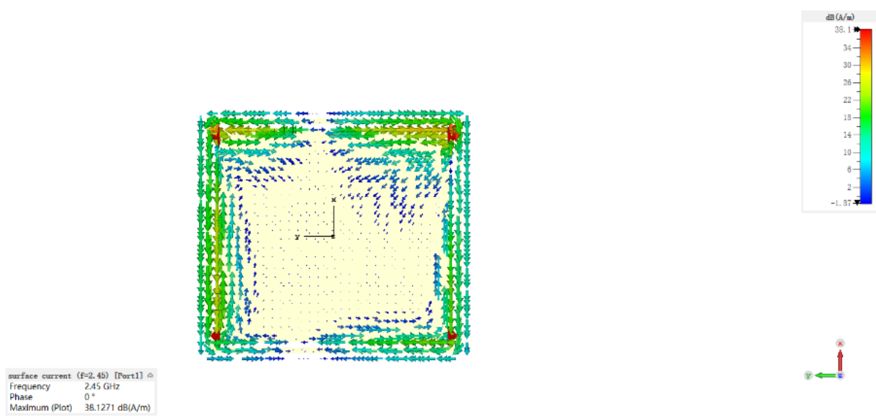


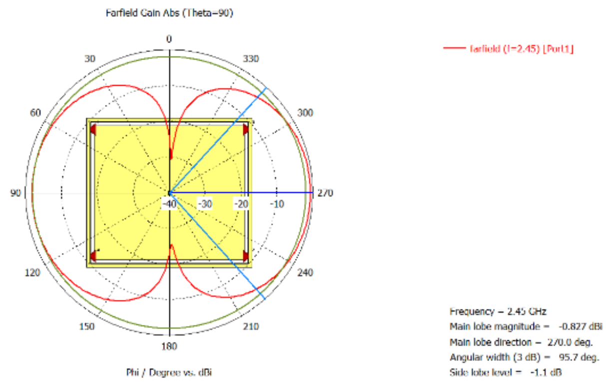
(b)



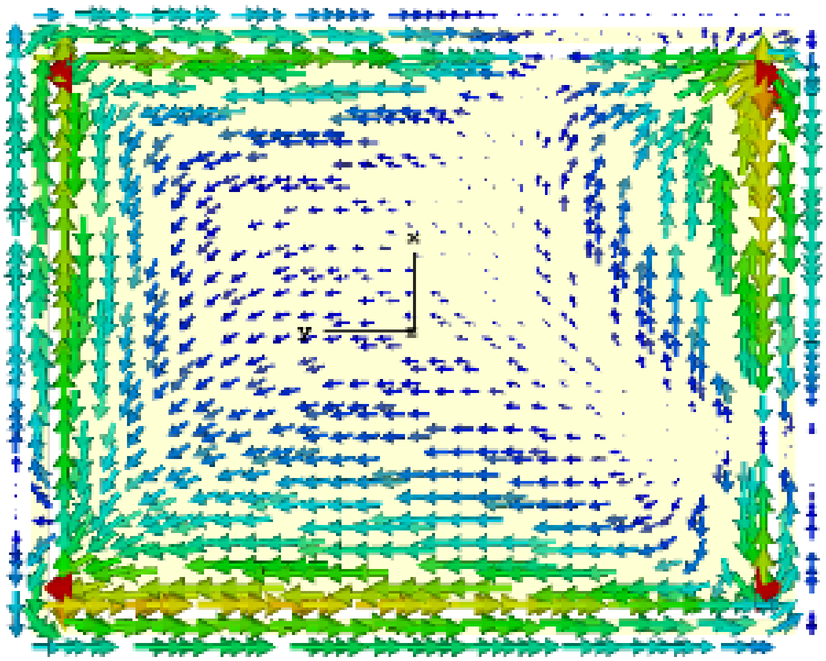
(c)

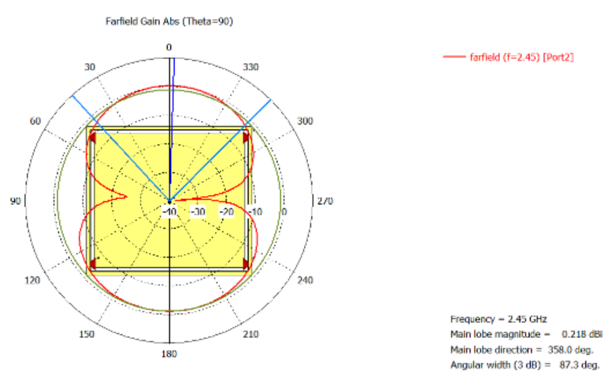
Fig. 4 *matched S-parameters and efficiency. (a) matching circuits. (b) matched S-parameters. (c) matched efficiency of Port1 and Port2.*




Farfield Gain Abs (Theta=90)
farfield (f=2.45) [Port1]
Phi / Degree vs. dBi
Frequency = 2.45 GHz
Main lobe magnitude = -0.827 dBi
Main lobe direction = 270.0 deg.
Angular width (3 dB) = 95.7 deg.
Side lobe level = -1.1 dB

(a)

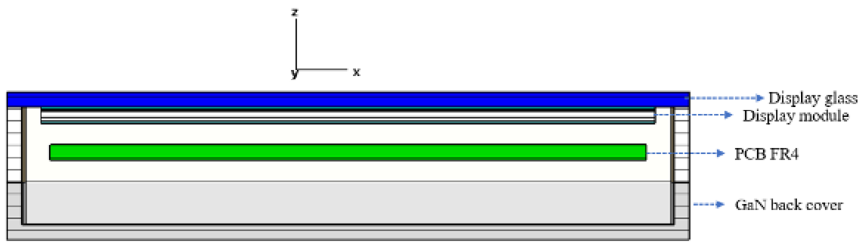



Farfield Gain Abs (Theta=90)
farfield (f=2.45) [Port2]
Phi / Degree vs. dBi
Frequency = 2.45 GHz
Main lobe magnitude = 0.218 dBi
Main lobe direction = 358.0 deg.
Angular width (3 dB) = 87.3 deg.
Side lobe level = -1.5 dB

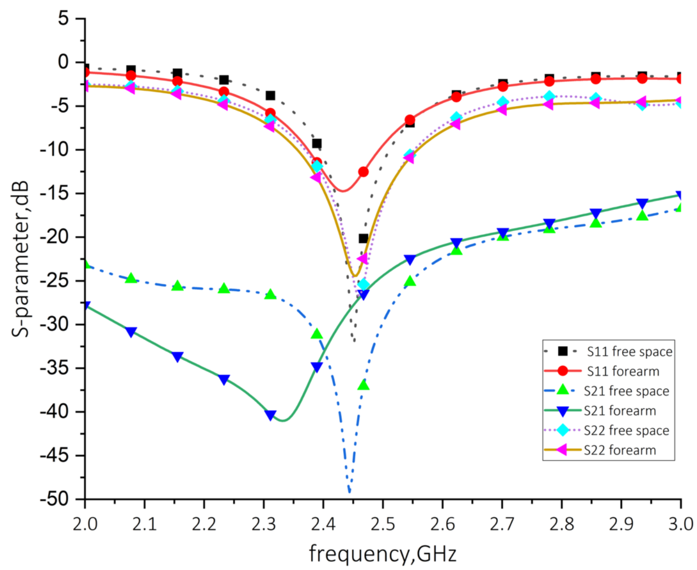
(b)

Fig. 5 *matched 2.45GHz current and radiation pattern. (a) current distribution and XOY plane radiation pattern of Port1. (b) current distribution and XOY plane radiation pattern of Port2.*

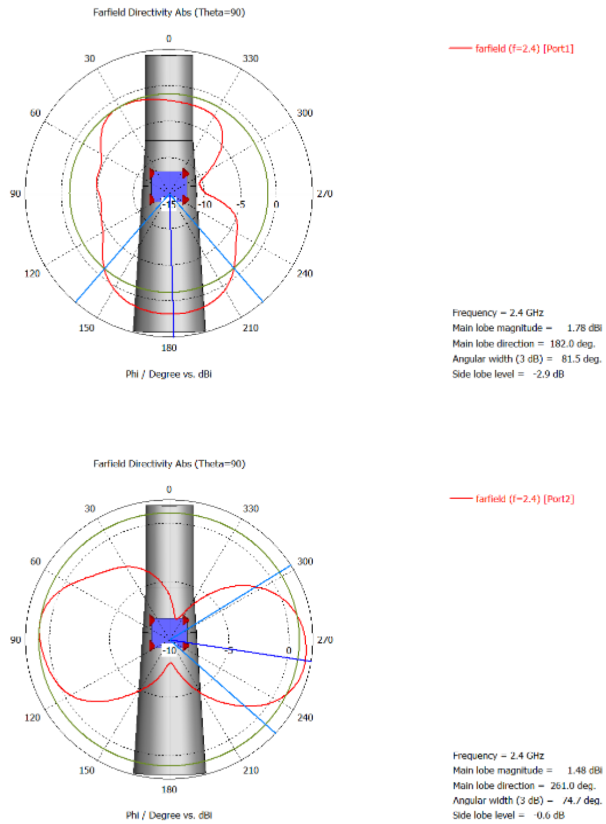
Forearm effects: Further, a typical smart watch is modelling in Fig.6a, adding display module, PCB FR4 material, and back cover. The relative permittivity [7] of GaN back-cover isε_r=10.6, tan δ=0.3, for wireless power applications. Fig.6b presents that forearm can significantly lower S21 notch frequency, and influences impedance of Port1.But it has a little effect on impedance of Port2, because of its radiation pattern orthogonal to the forearm. Combining the two antennas, a good omnidirectional MIMO antenna in spatial diversity can be obtained.



(a)



(b)



(c) (d)

Fig. 6 *matched current and 2.45GHz radiation pattern. (a) model of a typical smart watch. (b) S-parameters of free space and forearms loading. (c) XOY plane radiation pattern of Port1 with the forearm. (d) XOY plane radiation pattern of Port2 with the forearm.*

Conclusion: In this article, a simple but useful decoupling technique, which two radiation patterns have an orthogonal characteristic of 90-degree rotational symmetry, achieving a high isolation with 50dB, is proposed. A capacitive or inductive load is a function of frequency, the S21 notch frequency decreasing as the value of the capacitor or inductor increases. So, it is flexible to decouple for multiband applications with the variation of lumped elements if tunable switches for aperture tuning are available.

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