微波:過去及現在

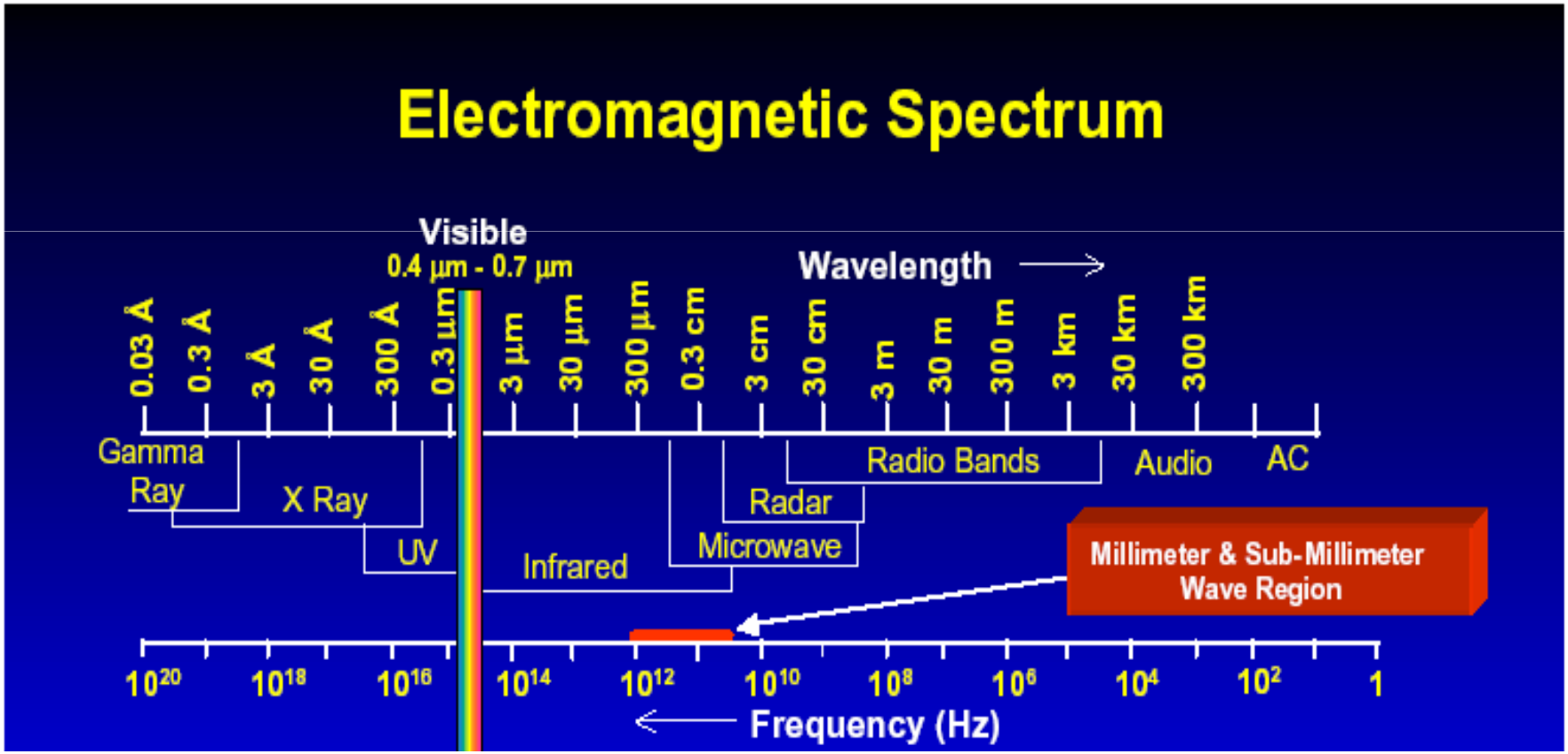
清華大學物理系
朱 國 瑞

我們首先對電磁波的基本物理及其寬廣的頻譜作一簡介，然後從光波談到微波。微波的波長介於1毫米和1米之間，它和大家的日常生活息息相關(電視、電話、手機、微波爐、衛星定位等)，是許多科學研究的基本工具(加速器、核融合等)，也是決定戰爭勝負的關鍵技術(雷達偵測、飛彈導航等)。最後以實例說明以上的種種應用，並略談國內高功率微波科技的動態。

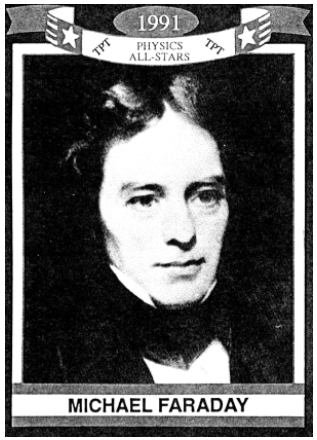
Microwaves Frequencies:

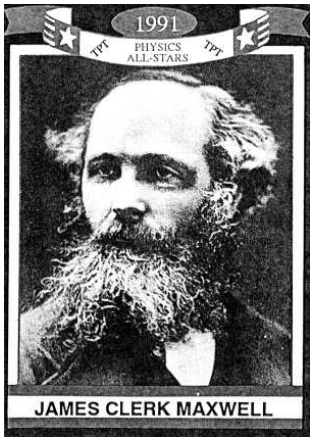
f = 0.3 GHz-300 GHz

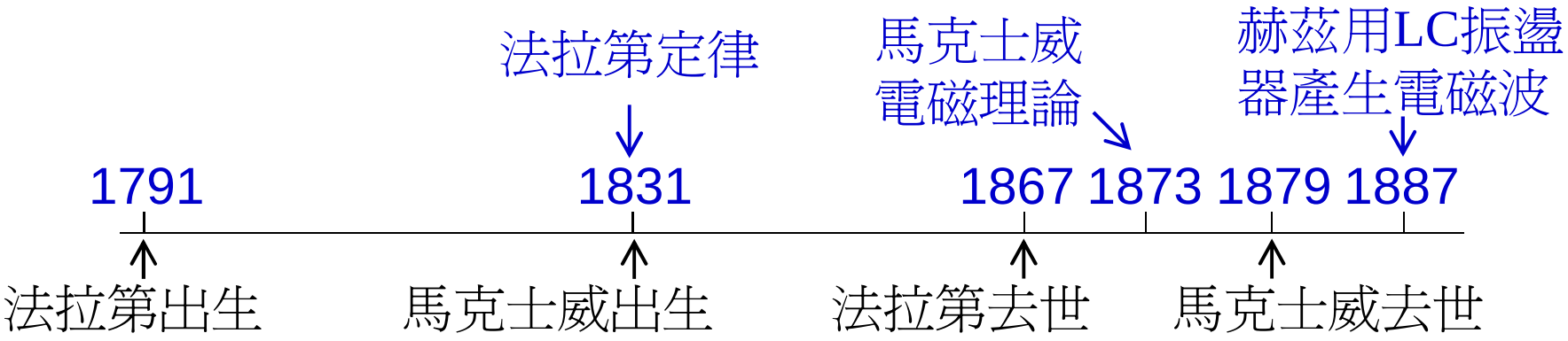
(corresponding to free space wavelengths of 100 cm-1 mm)



電磁波發展簡史

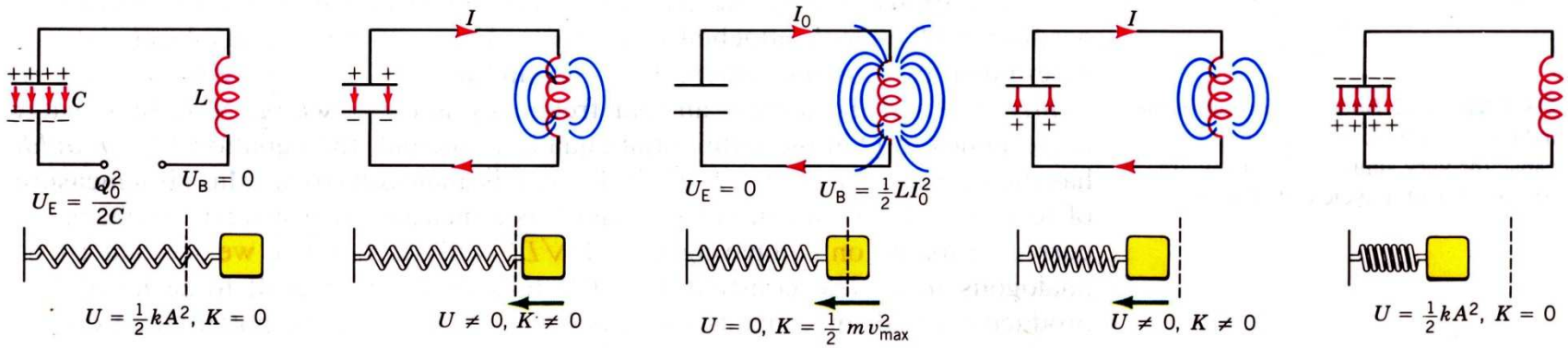






- 法 拉 第 ：隨時間變化的磁場(dB/dt)會產生電場
- 馬克士威：隨時間變化的電場(dE/dt)會產生磁場

「LC振盪」與「質塊+彈簧振盪」



(取材自H. Benson, “University Physics”)

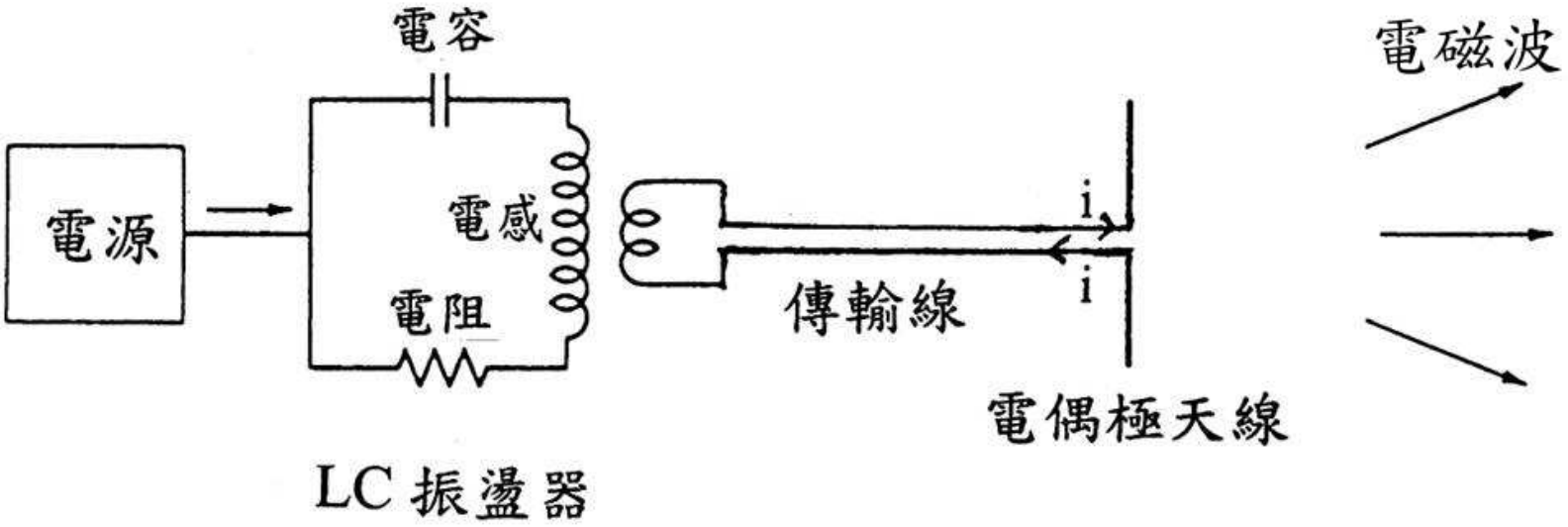
振盪現象的通則：**能量形式1 ↔ 能量形式2**

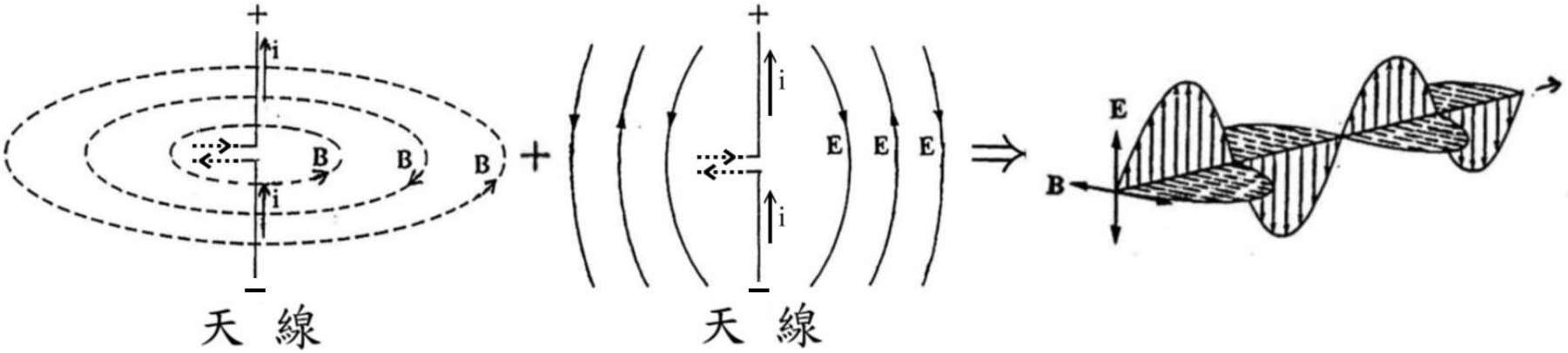
需要儲存能量的機制

需要交換能量的機制

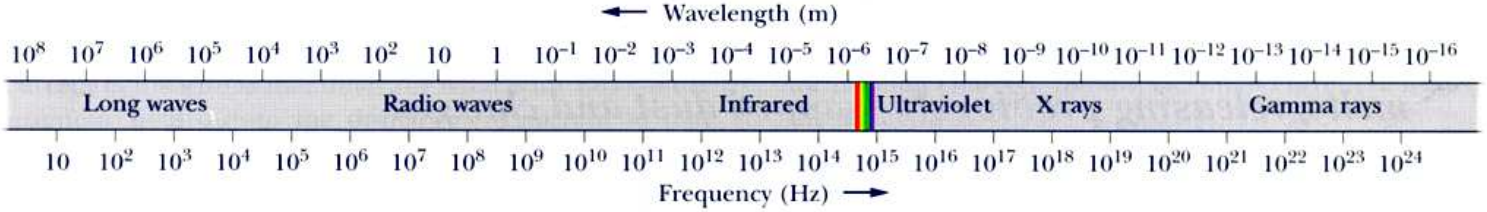
	能量儲存機制	能量交換機制	介　質
質塊+彈簧	動能，位能	復原力	質塊及彈簧
LC振量器	電場，磁場	電流	L, C及導線
電磁波	電場，磁場	$\frac{dB}{dt}, \frac{dE}{dt}$	無

電磁波的產生舉例:電偶極天線

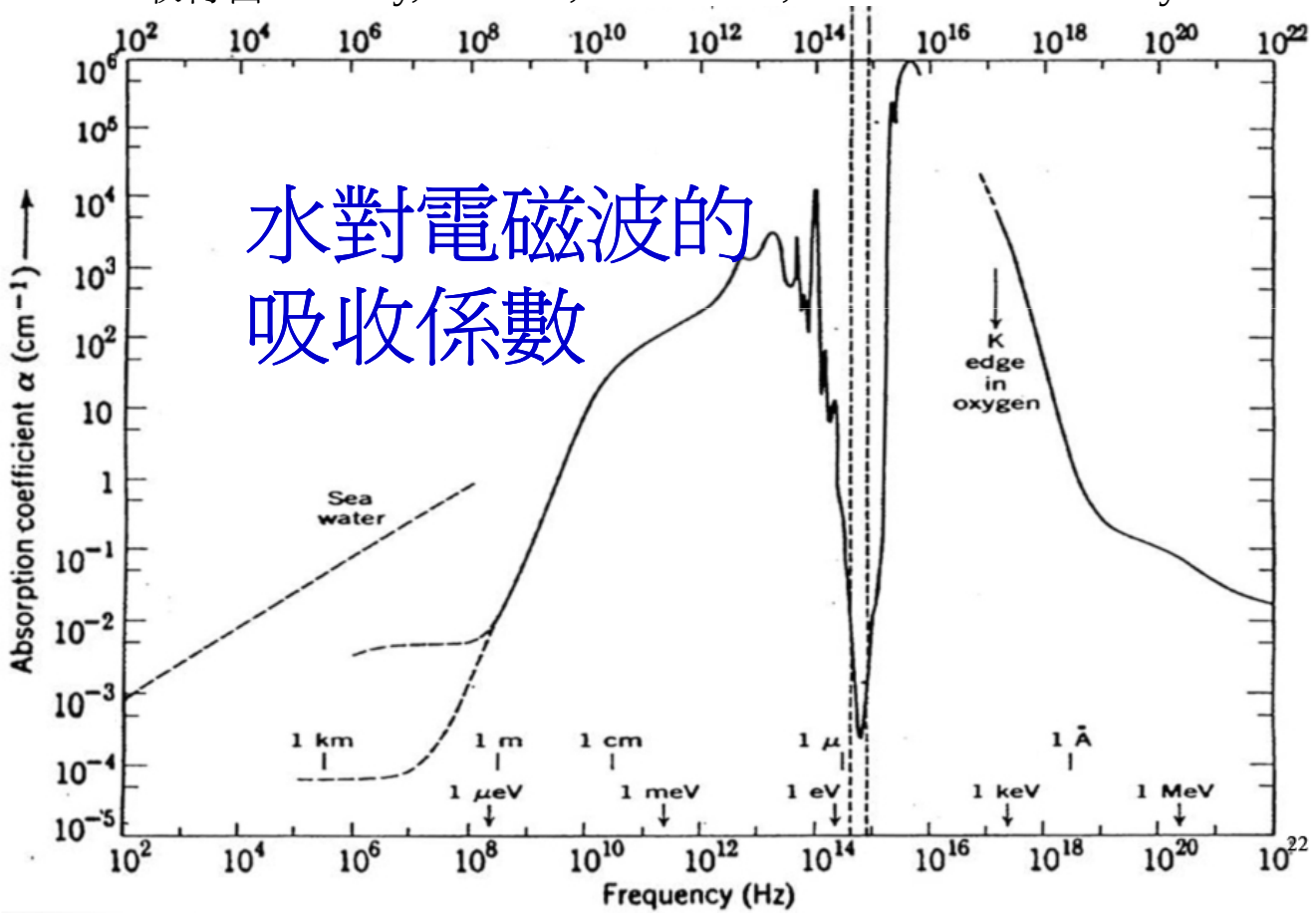




電磁波頻段

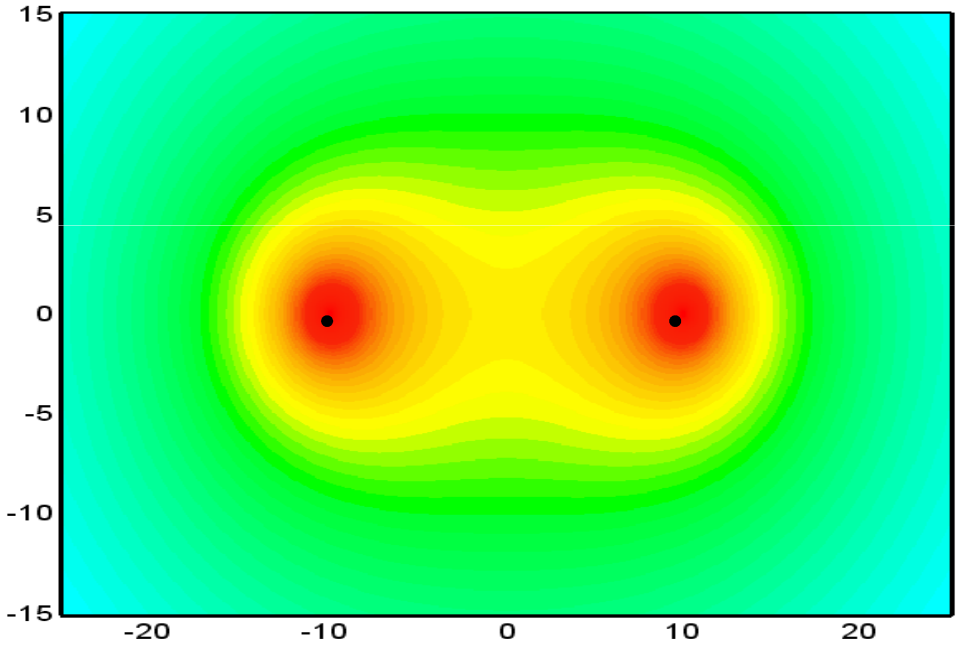


取材自Halliday, Resnick, and Walker, “Fundamentals of Physics”



取材自J. D. Jackson, “Classical Electrodynamics”

高壓線如何傳輸能量



美國物理學會公共事務聲明
(1995.4.23, 2005.4.15)

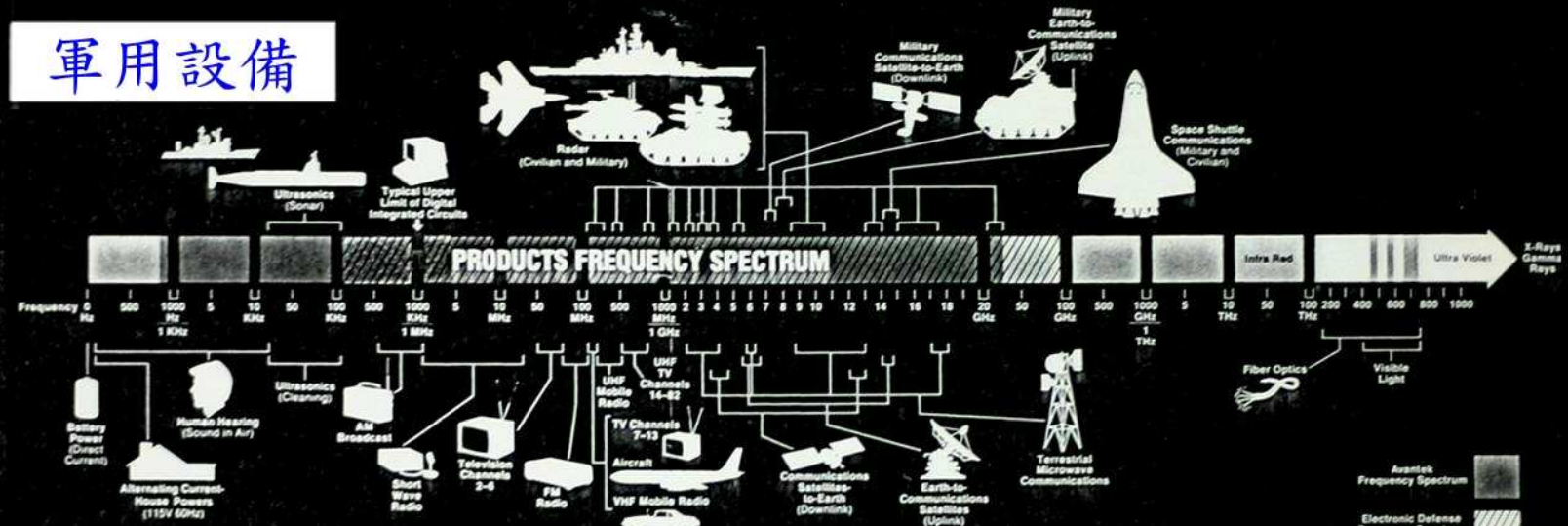
“高壓線導致癌症的臆測尚無科學證據。”

“The conjectures relating cancer to power line fields have not been scientifically substantiated.”

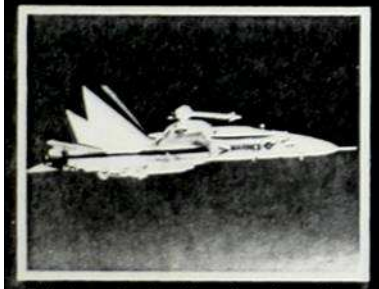
(http://www.aps.org/statements/index.cfm)

雷達及通訊頻道

軍用設備



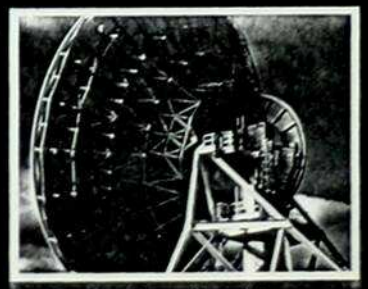
民用設備



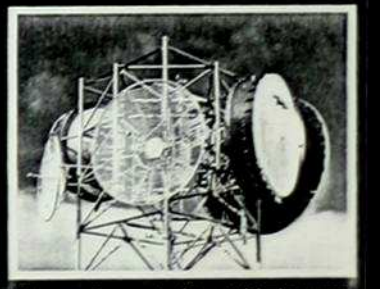
Today's combat aircraft employ at least five or six major electronic systems, most of which incorporate microwave components.

Navy combat and intelligence ships carry a vast array of communications, radar and defense systems, including eight to ten major systems employing microwave products.

Many armored vehicles carry acquisition radar and electronic countermeasures systems employing microwave products.

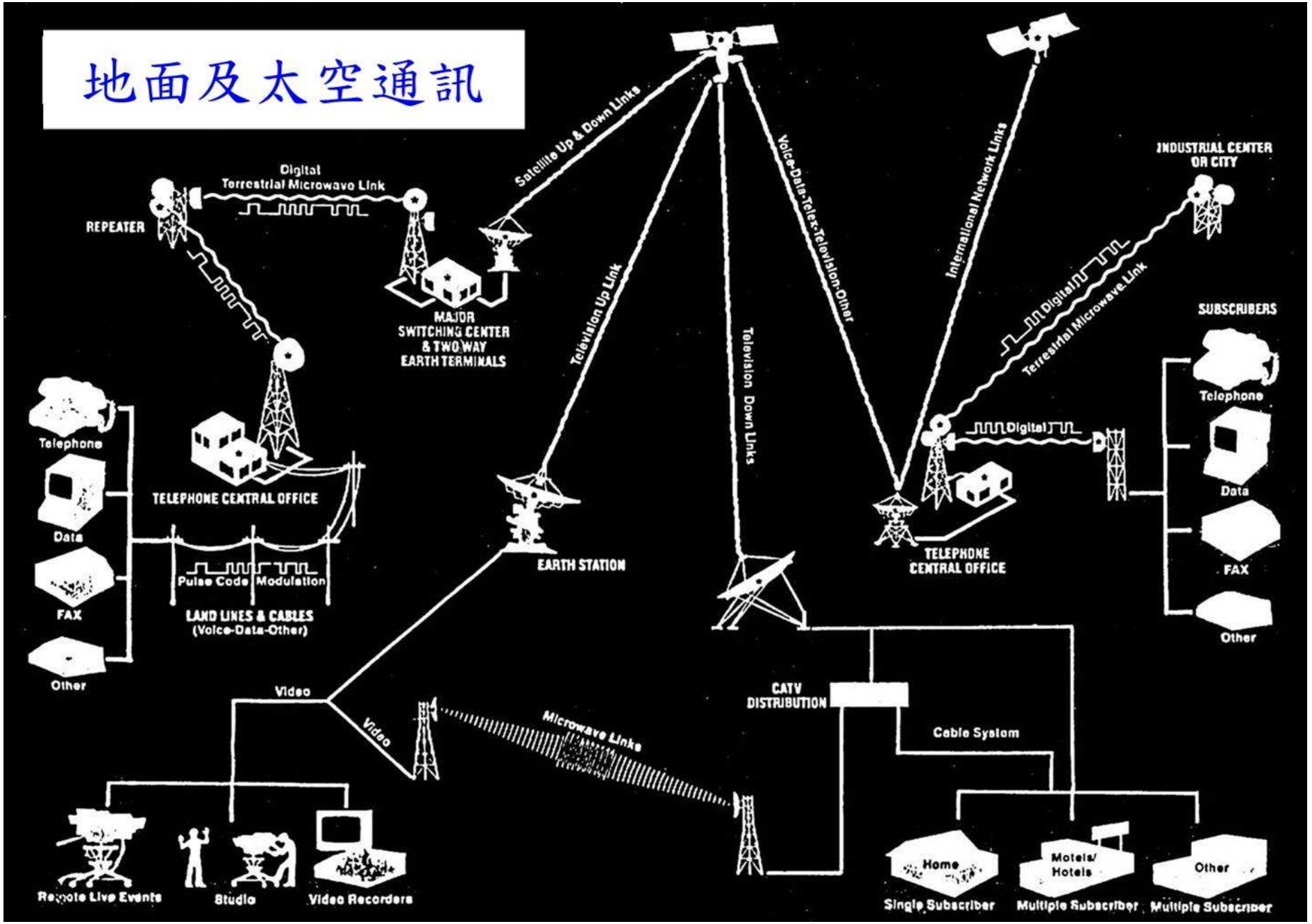


Earth stations of every size and shape are built around microwave technology. Each one incorporates many different microwave products.

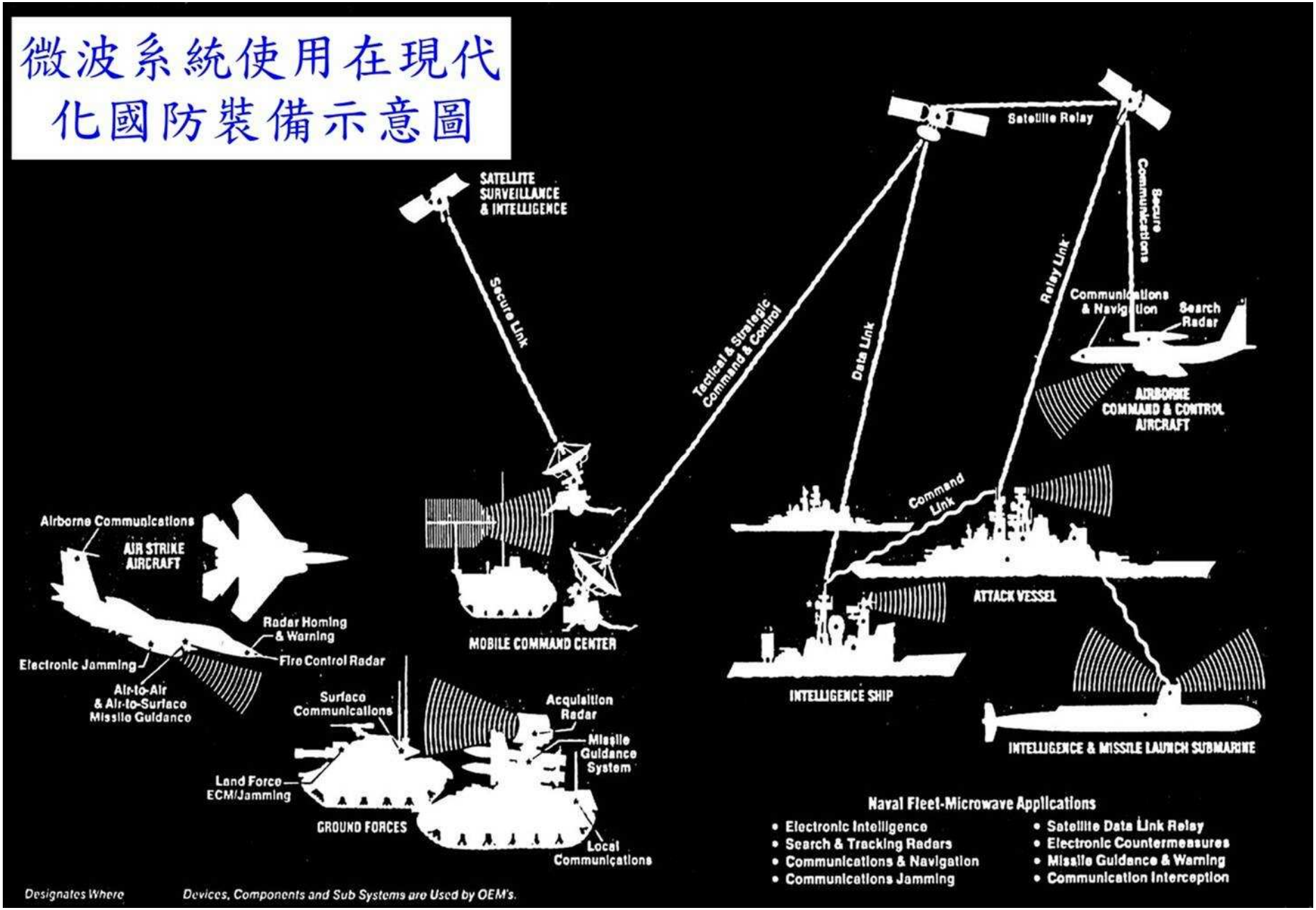


There are thousands of terrestrial microwave relay systems in operation today—each of which uses microwave components and systems.

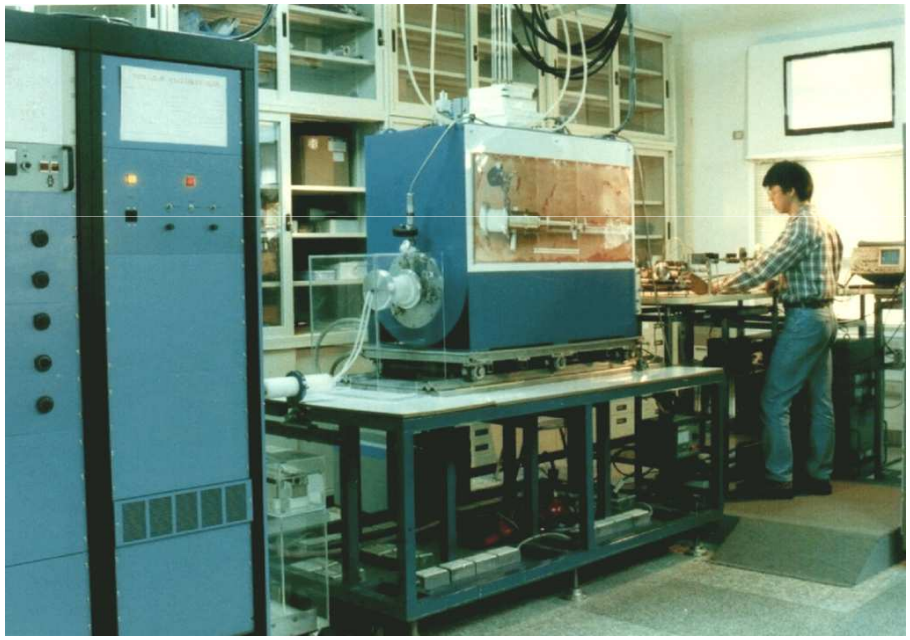
地面及太空通訊

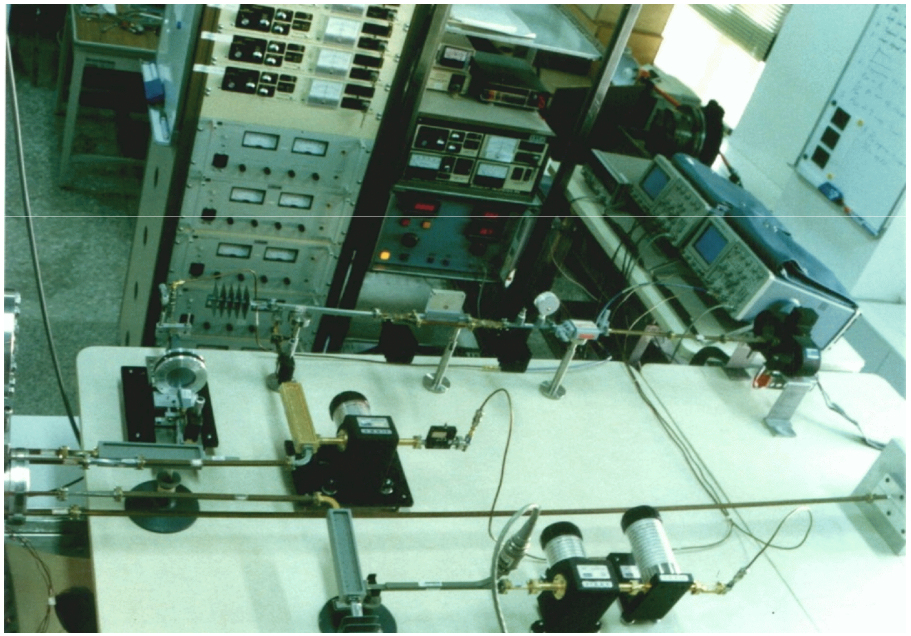

Digital
Terrestrial Microwave Link
REPEATER
Satellite Up & Down Links
MAJOR
SWITCHING CENTER
& TWO WAY
EARTH TERMINALS
Television Up Link
Television Down Links
Voice-Data-Telex-Television-Other
International Network Links
INDUSTRIAL CENTER
OR CITY
Digital
Terrestrial Microwave Link
SUBSCRIBERS
Telephone
Data
FAX
Other
Digital
TELEPHONE CENTRAL OFFICE
Pulse Code Modulation
LAND LINES & CABLES
(Voice-Data-Other)
EARTH STATION
TELEPHONE
CENTRAL OFFICE
Video
Video
Microwave Links
CATV
DISTRIBUTION
Cable System
Remote Live Events
Studio
Video Recorders
Home
Motels/
Hotels
Other
Single Subscriber
Multiple Subscriber
Multiple Subscriber

微波系統使用在現代化國防裝備示意圖

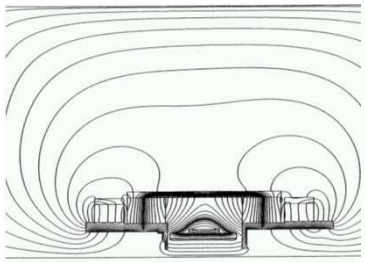


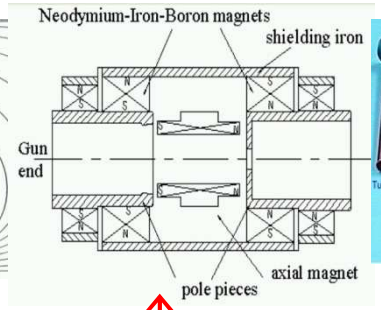
清華大學「高頻電磁實驗室」

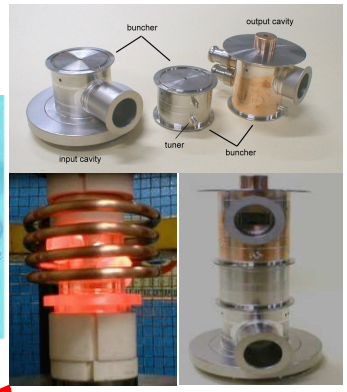




微波發射器製程







電腦
模擬

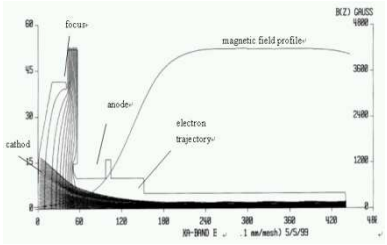
工程
設計

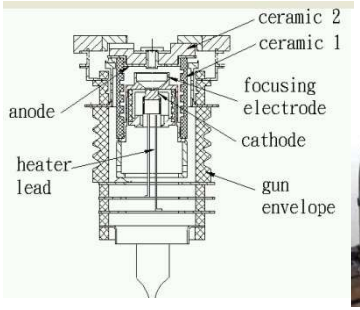
精密
加工

組件
焊接

組裝
成品

成品
測試





"University Training of Tube Engineers in the US and broad," plenary paper presented at IVEC, 2006 by Dr. G. Caryotakis, Head, Klystron Department, SLAC

University Training in Vacuum Electronics (Europe and Asia)

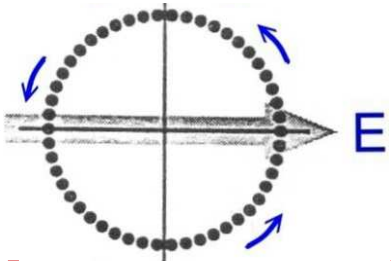
	Japan	Germany	France	UK	China	Korea	Taiwan	India	Russia	Israel
Are Vacuum Electronics courses offered?	YES (as part of plasma science)	YES U of Karlsruhe	NO Graduate Courses	YES	YES	YES	YES	YES	YES	YES
Practical training university facilities?	SOME EXP. FACILITIES	YES	No	YES	YES	YES	YES	YES	YES	SOME
Adequate employment?	NO	Thales at Ulm. But most go to Solid State	Few industrial jobs Research labs	SOME	YES	YES	YES		Low salaries	FEW IN MW INDUSTRY
Interaction with industry?	SOME INTERACTION	Only via professional Societies	No	YES	YES	YES	YES		Somewhat	"LOW LEVEL "
How many PhD degrees last year?	10	5	2	5	30-50	4	1	5	10	5
Overall rank (Highly subjective)	7	9	10	8	1	2	3	5	6	4

Survey Results –Countries in Order of Descending GDP

Principle of the Electron Cyclotron Maser – a Relativistic Bunching Mechanism

gain energy,
rotate slower

$$\Omega_c = \frac{eB_0}{\gamma m}$$

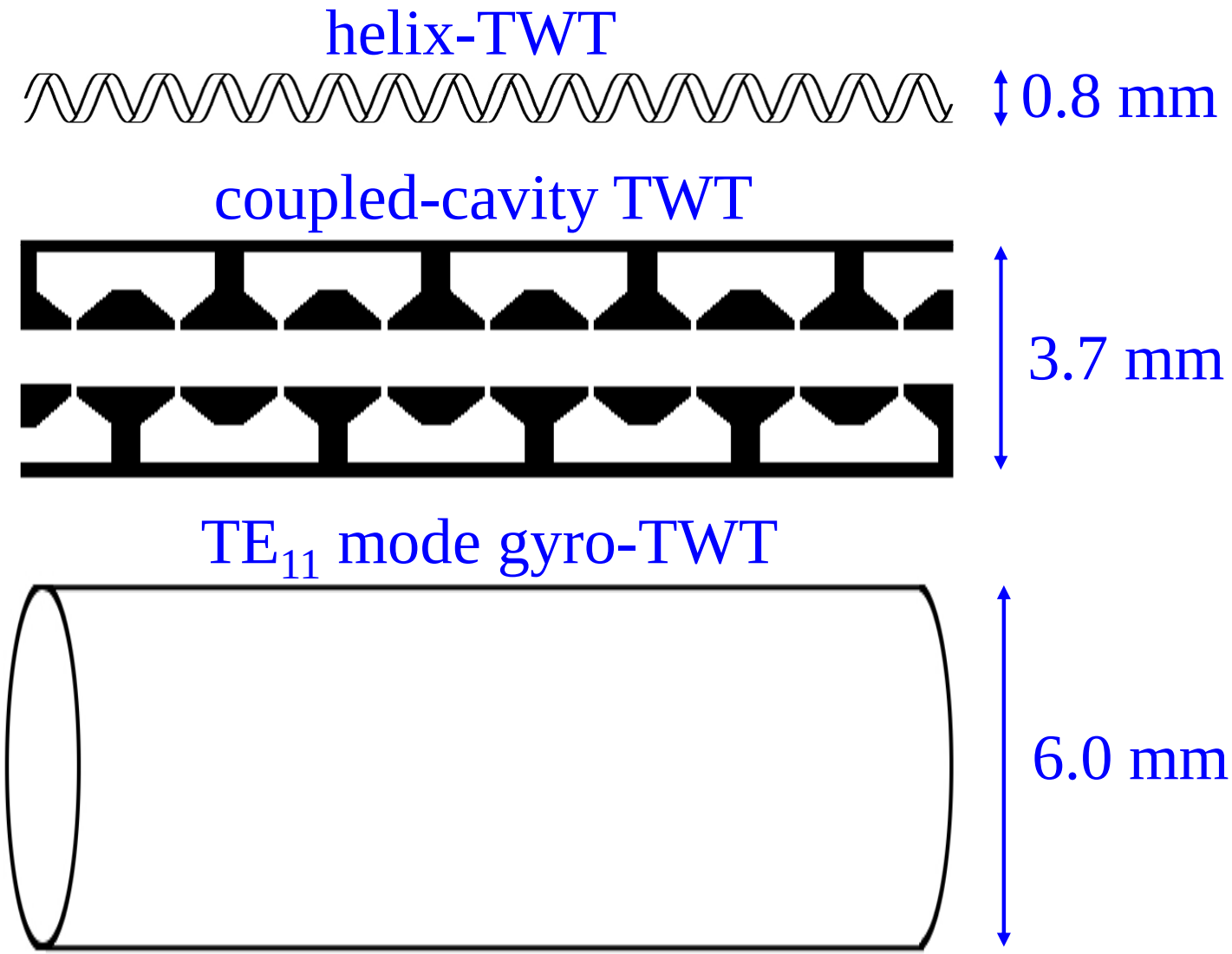


azimuthal
bunching

lose energy,
rotate faster

Electron dynamics in a 37 GHz,
TE_{01} mode gyrotron oscillator

Shape and Dimension Comparison of 30 GHz Traveling-Wave Amplifier Circuits

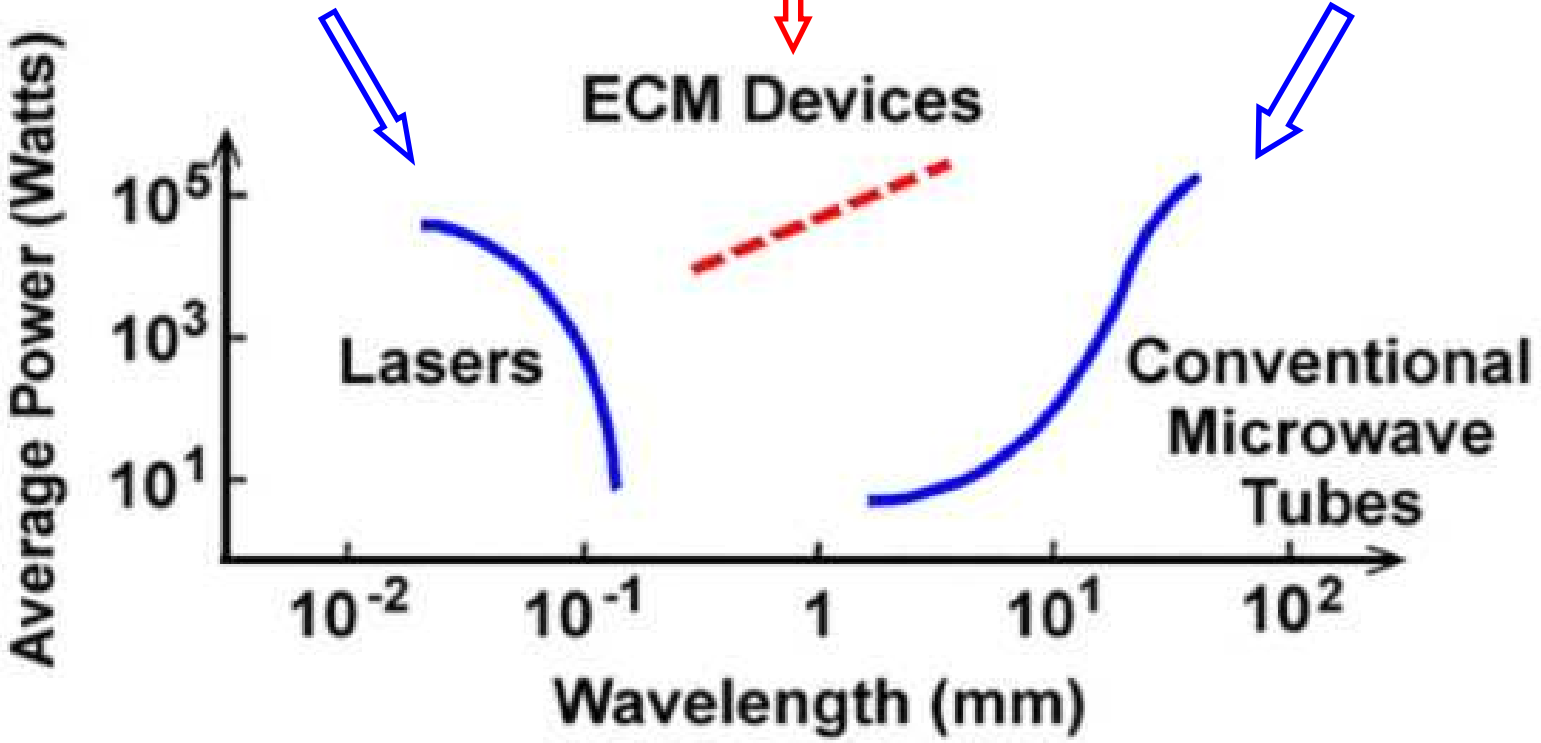


Significance of ECM-Based Devices

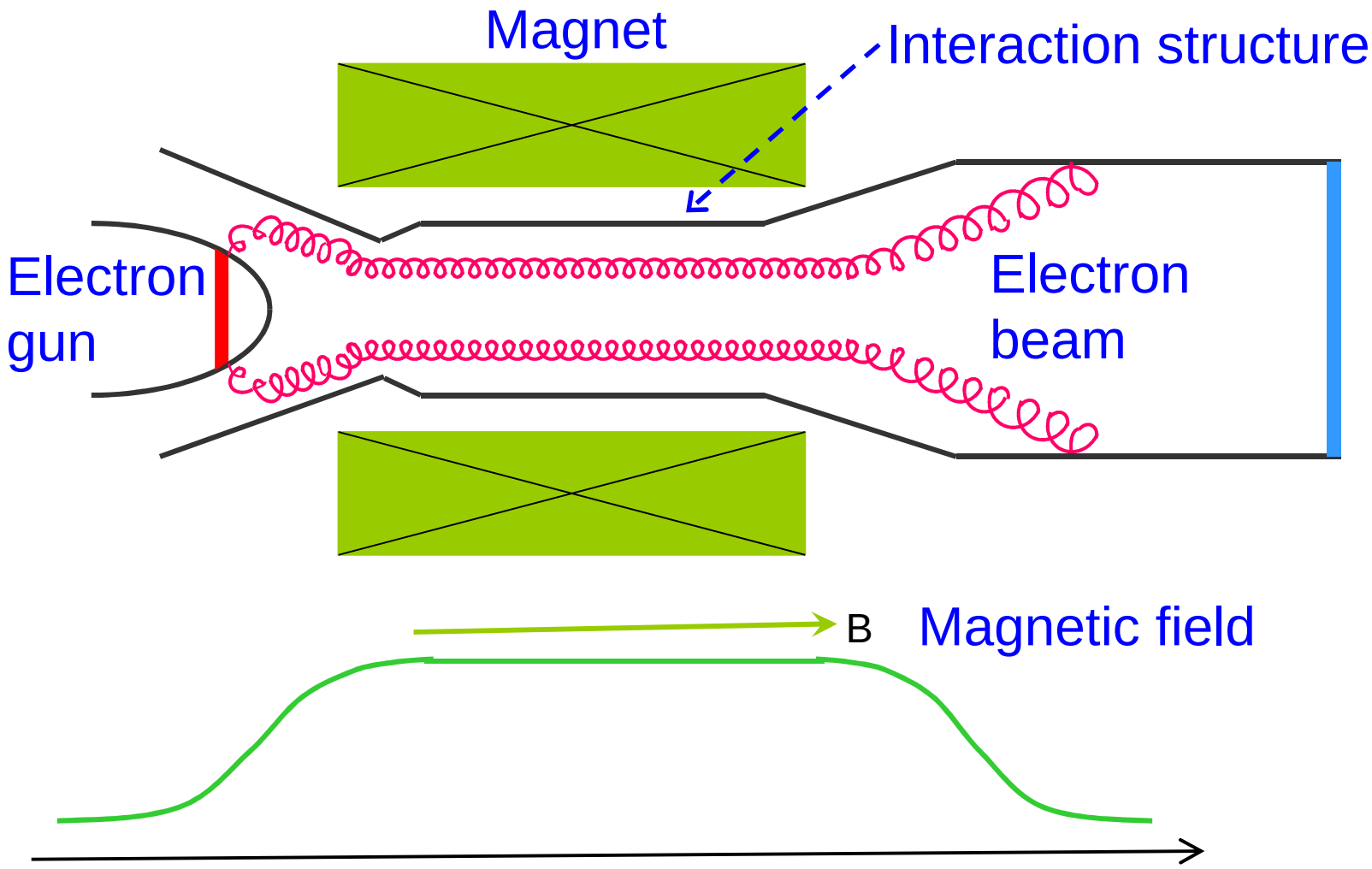
one photon per excitation, large interaction space

multiple photon per electron, large interaction space

multiple photon per excitation, interaction space ~ wavelength



ECM-Based Devices (Gyrotrons)



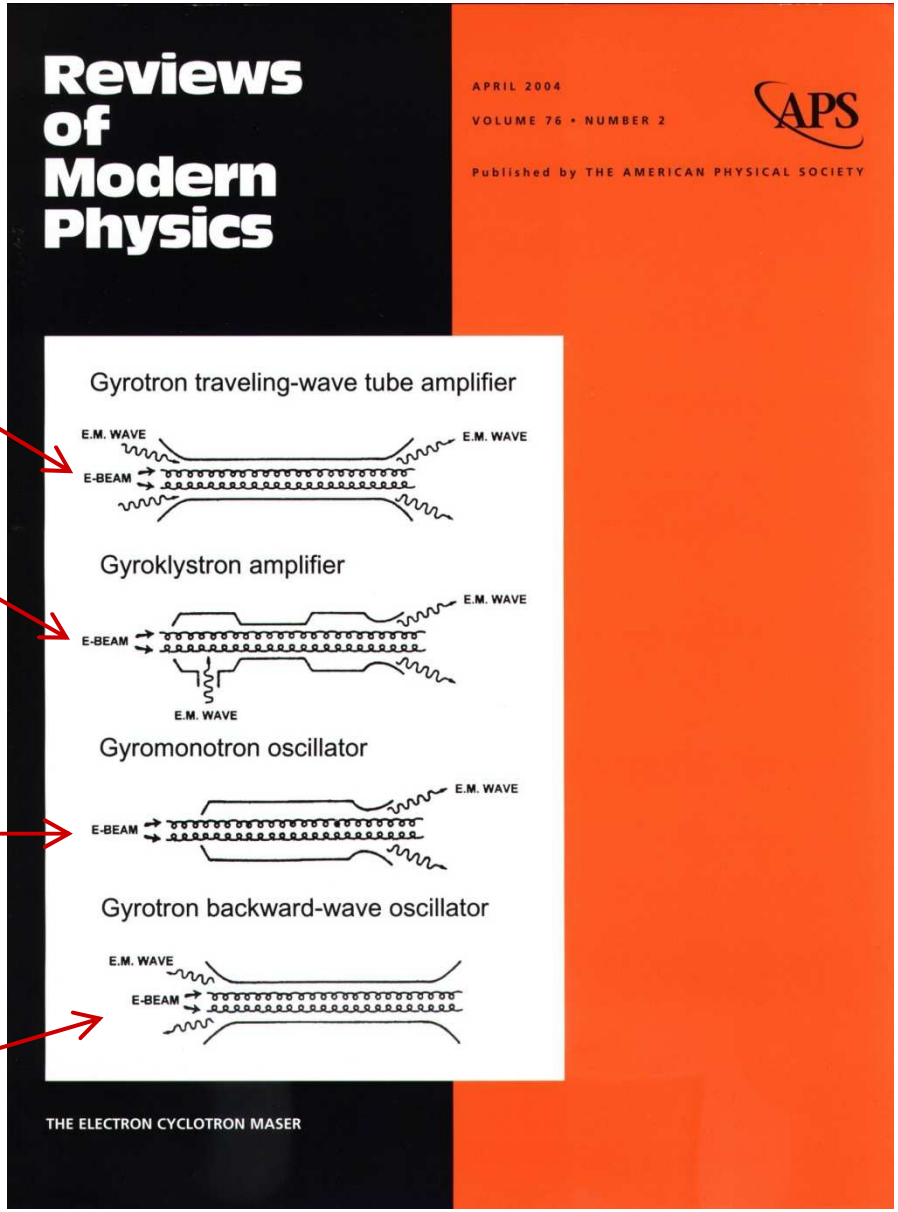
Types of ECM-Based Devices

Phase control
Broad bandwidth
High-resolution space radar

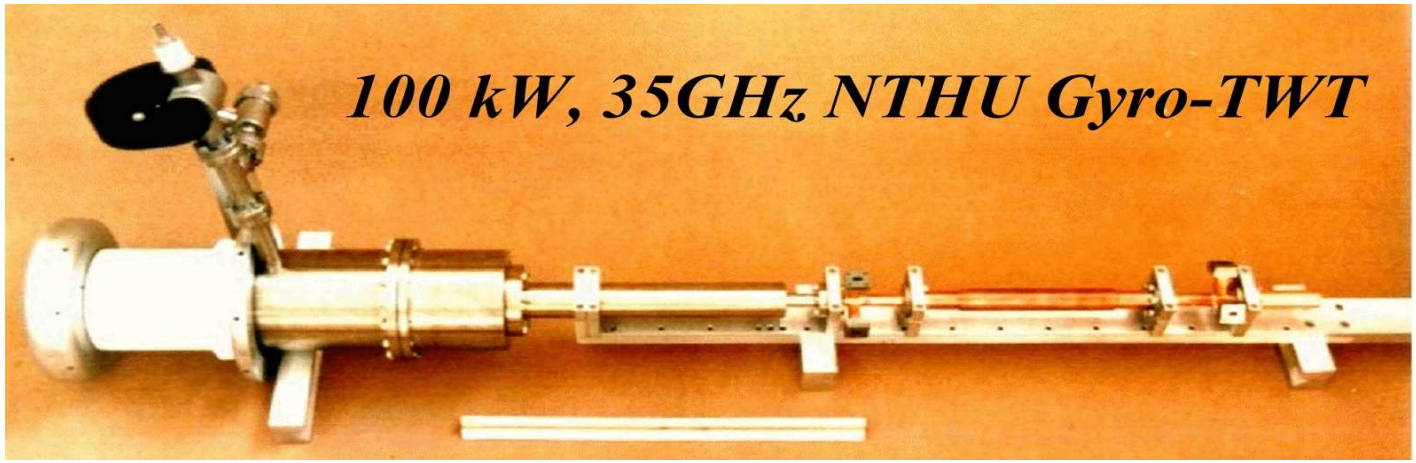
Phase control
Narrow bandwidth
Particle acceleration
Space radar

High average power
Fusion plasma heating
Industrial processing

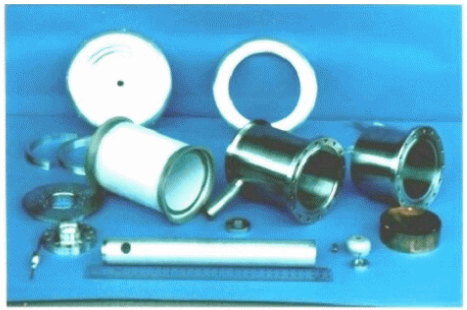
Continuous frequency tunability
Not yet exploited

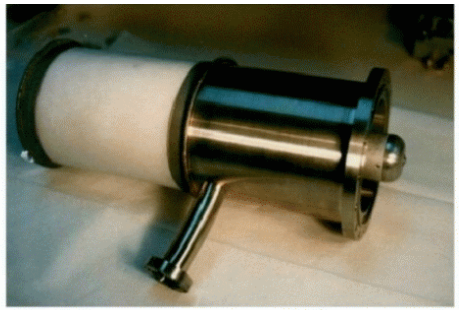


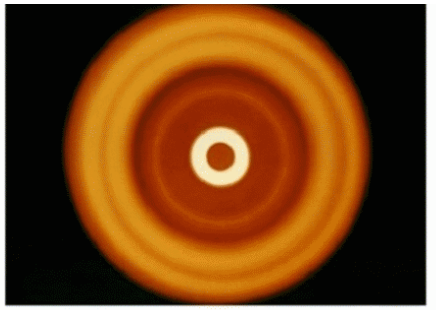
磁旋行波放大器



單陽極磁控電子鎗



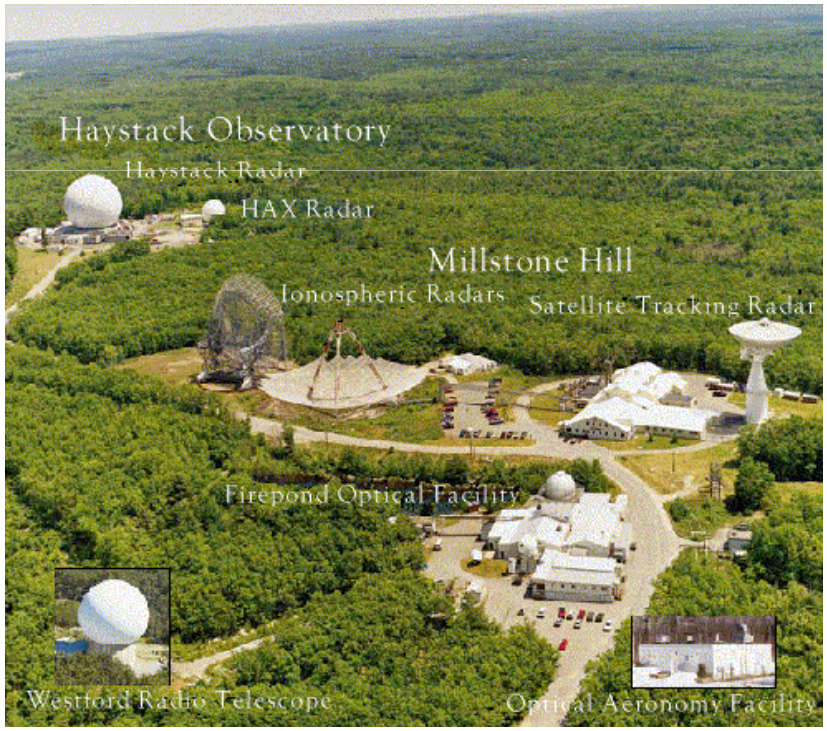




	尖峯功率	效率	增益	頻寬
磁旋行波放大器	93 kW	26.5 %	70 dB	8.6 %
傳統行波放大器	50 kW	16 %	40 dB	6 %

太空偵測設施

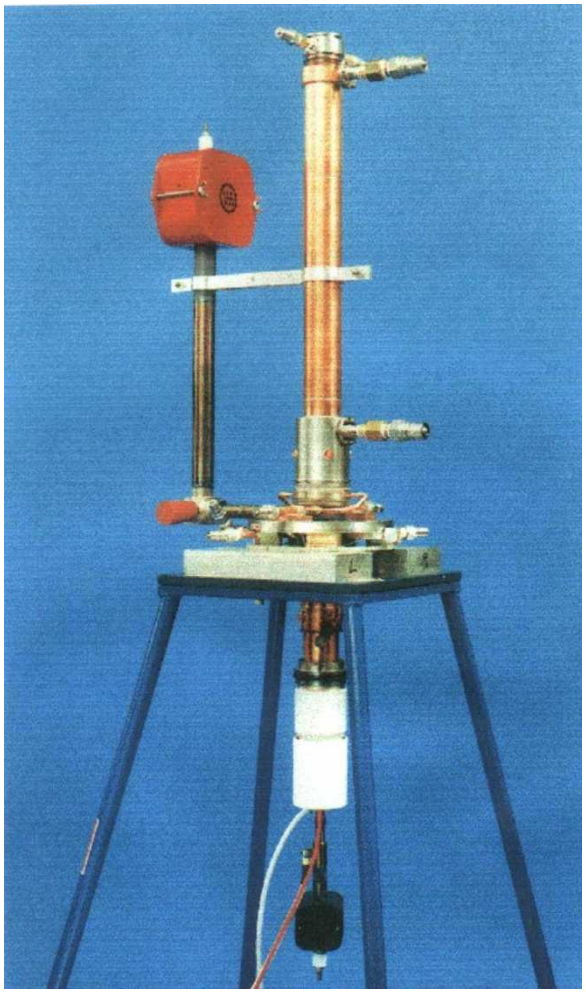
美國MIT林肯實驗室 Haystack radar



美國陸軍Kwajalein Atoll雷達測試場

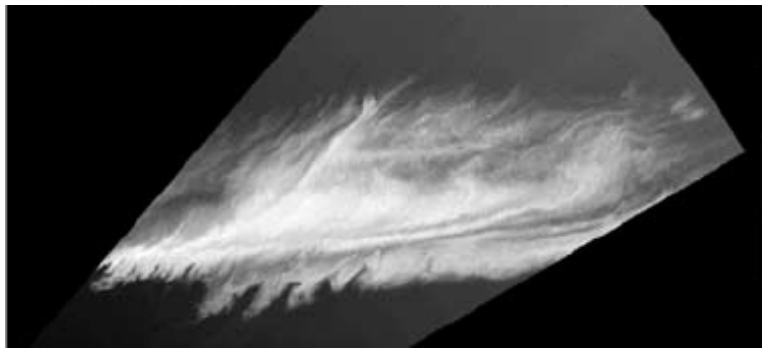
Gyroklystron and Applications

94 GHz, 100 kW Gyroklystron
US Naval Research Laboratory

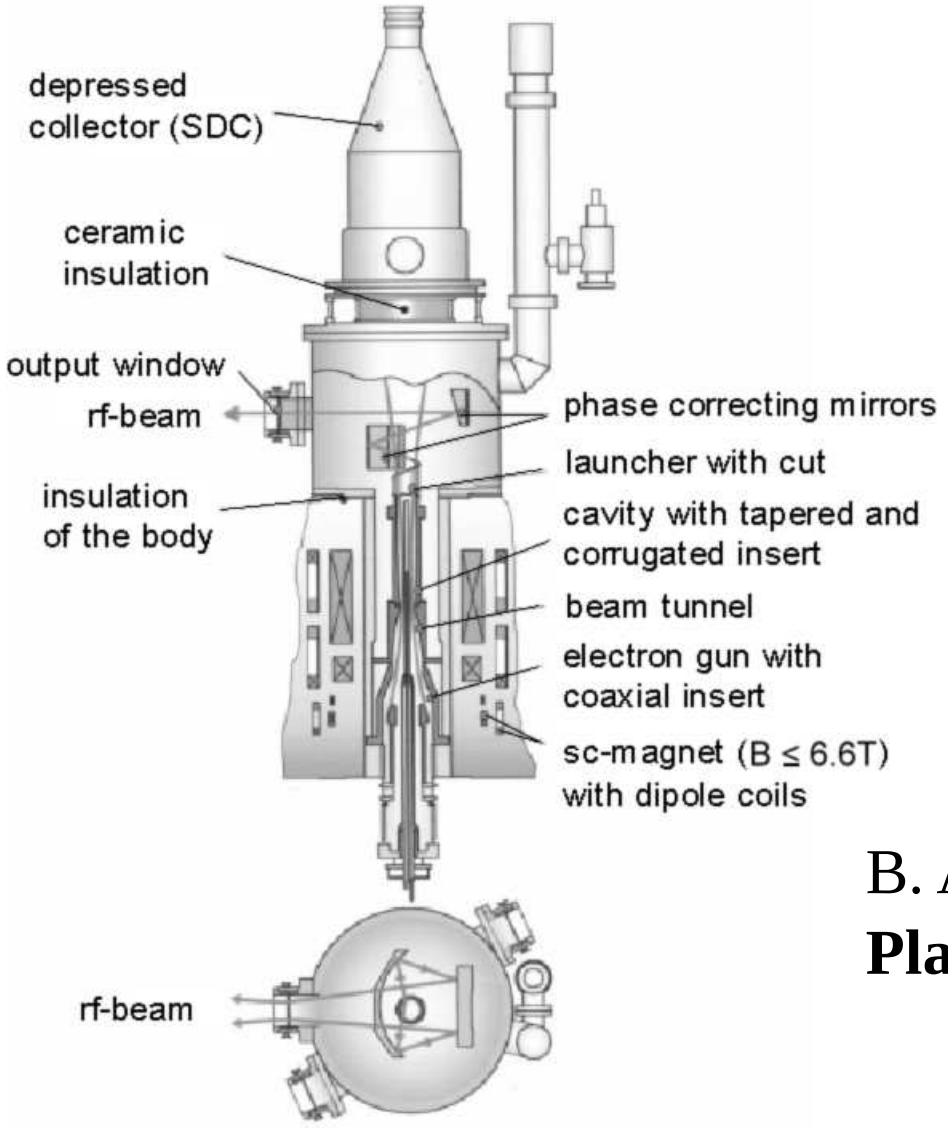


W-band Advanced Radar for Low Observable Control (WARLOC)

Radar image of cloud from the WARLOC



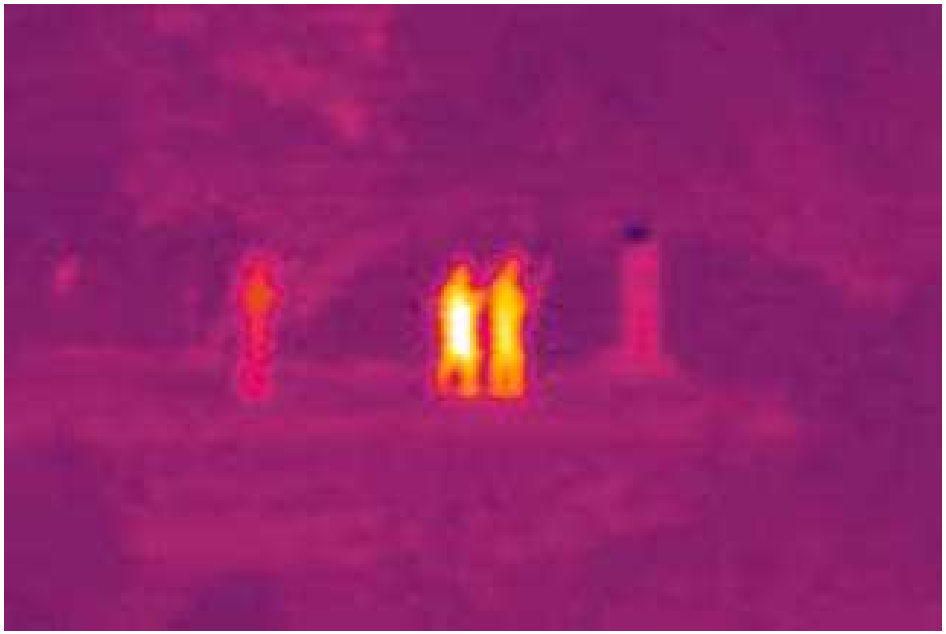
A MW Gyromonotron Oscillator



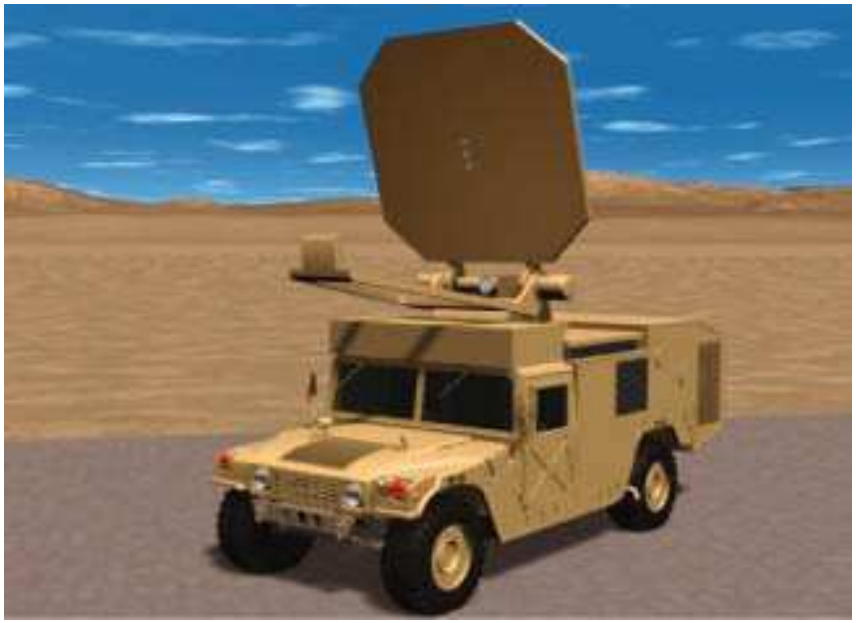
165 GHz, $TE_{31,17}$ mode, 2.2 MW coaxial gyromonotron for fusion plasma heating

B. A. Piosczyk *et al.*, **IEEE Trans. Plasma Sci. 30**, 819 (2002).

Application of W-band Gyromonotrons – Active Denial Technology (ADT)



Infrared image of silhouette targets

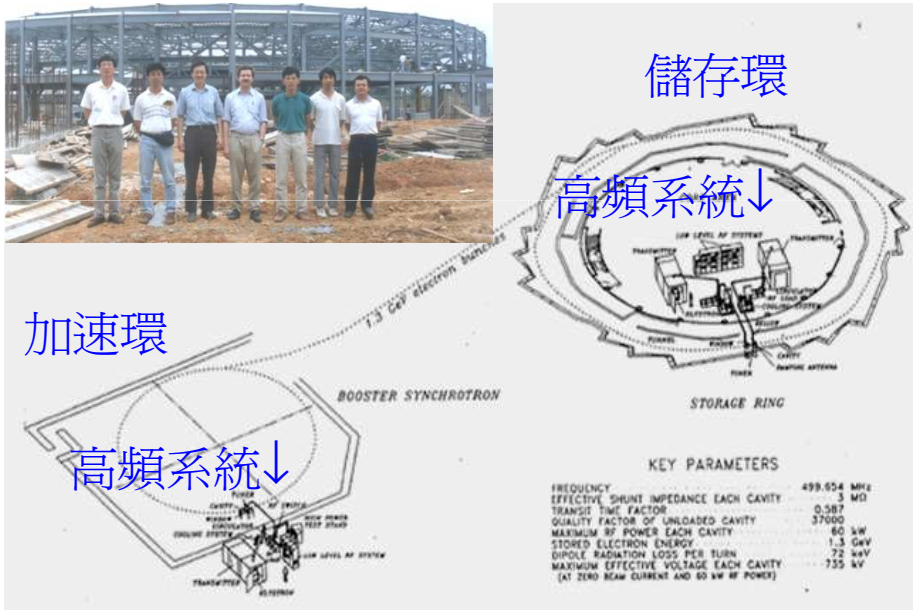


Vehicle-mounted ADT concept

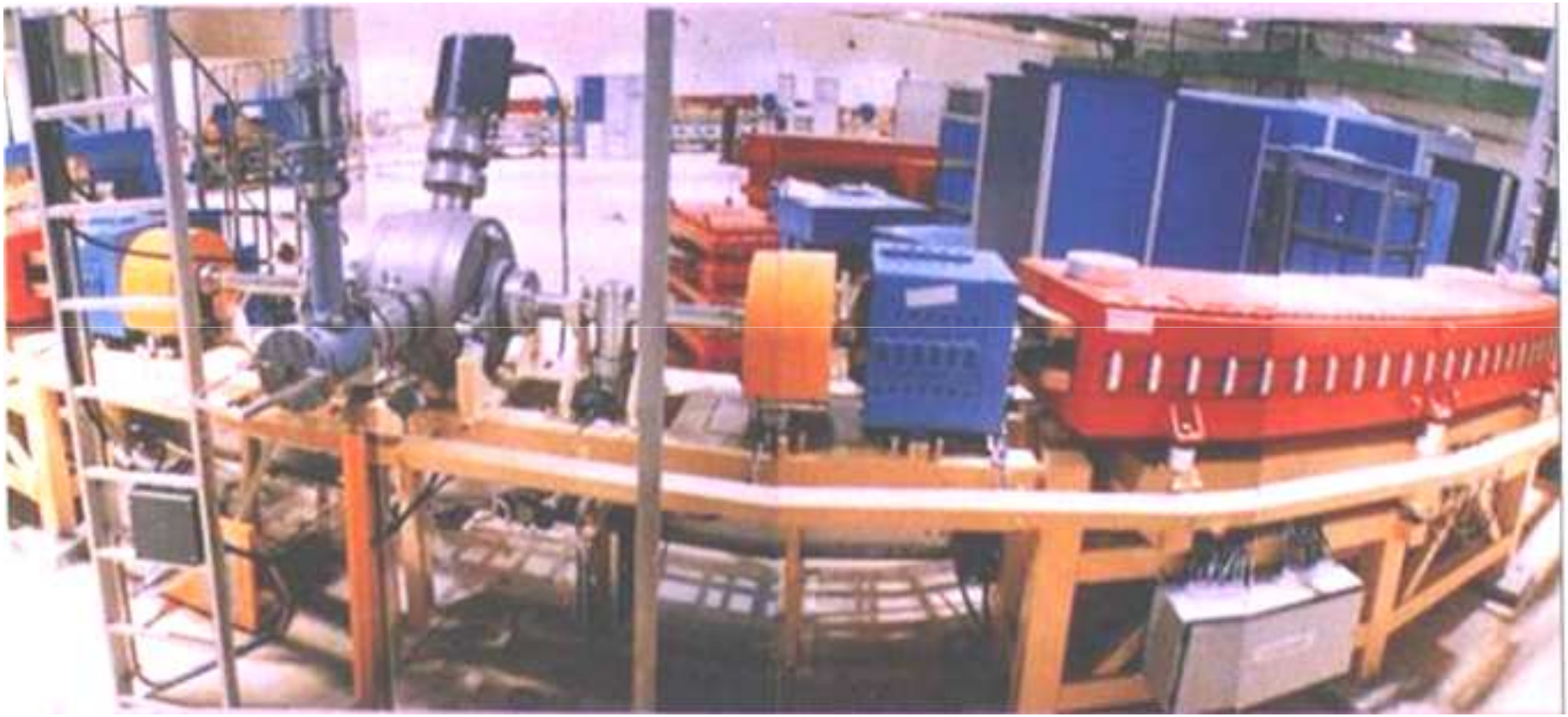
Application of THz Gyromonotrons – materials characterization, plasma imaging, medical diagnosis, etc.

Research Center for Development of Far-Infrared Region
University of Fukui, Japan

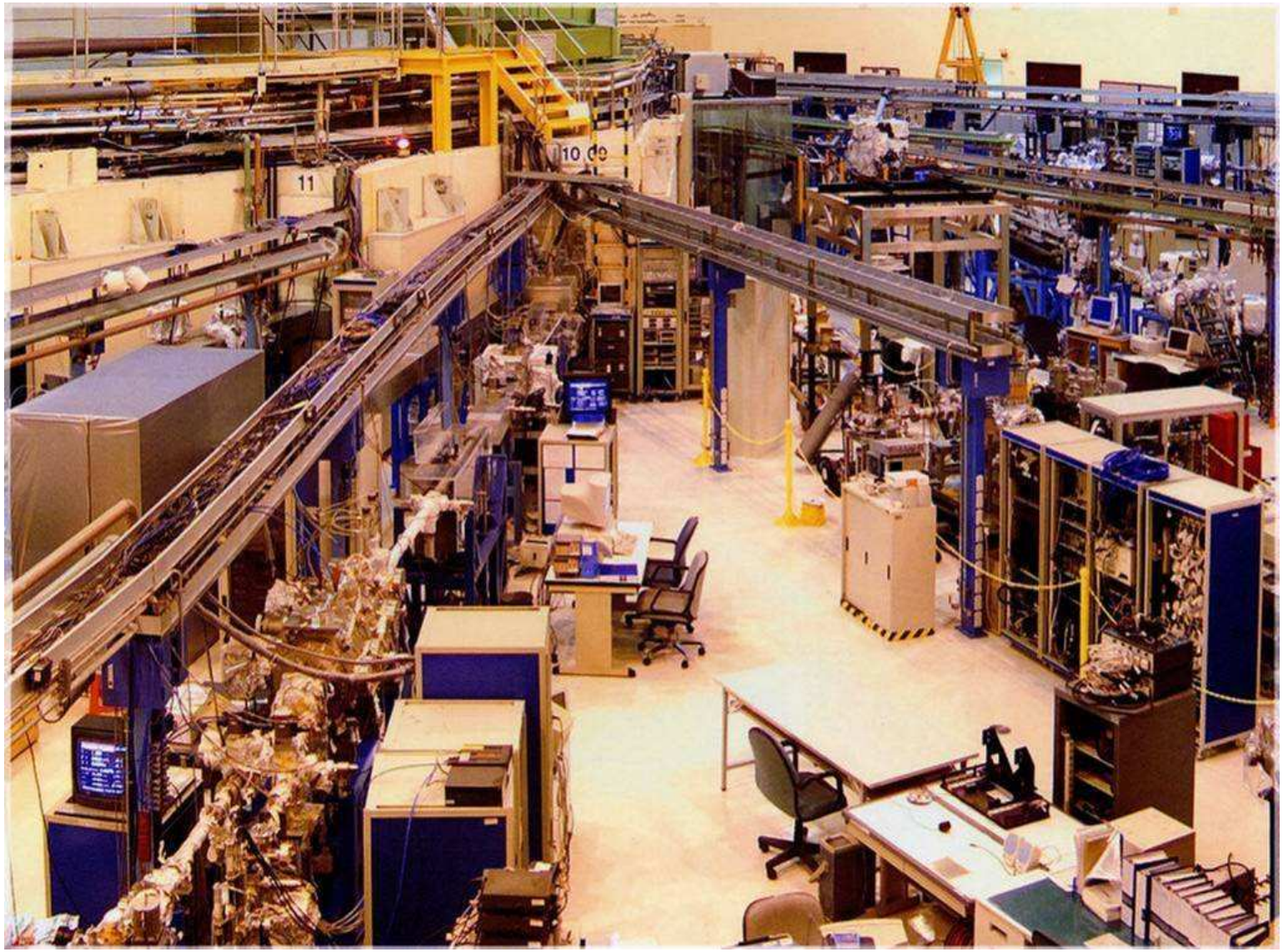
同步輻射研究中心
(位於新竹科學園區)



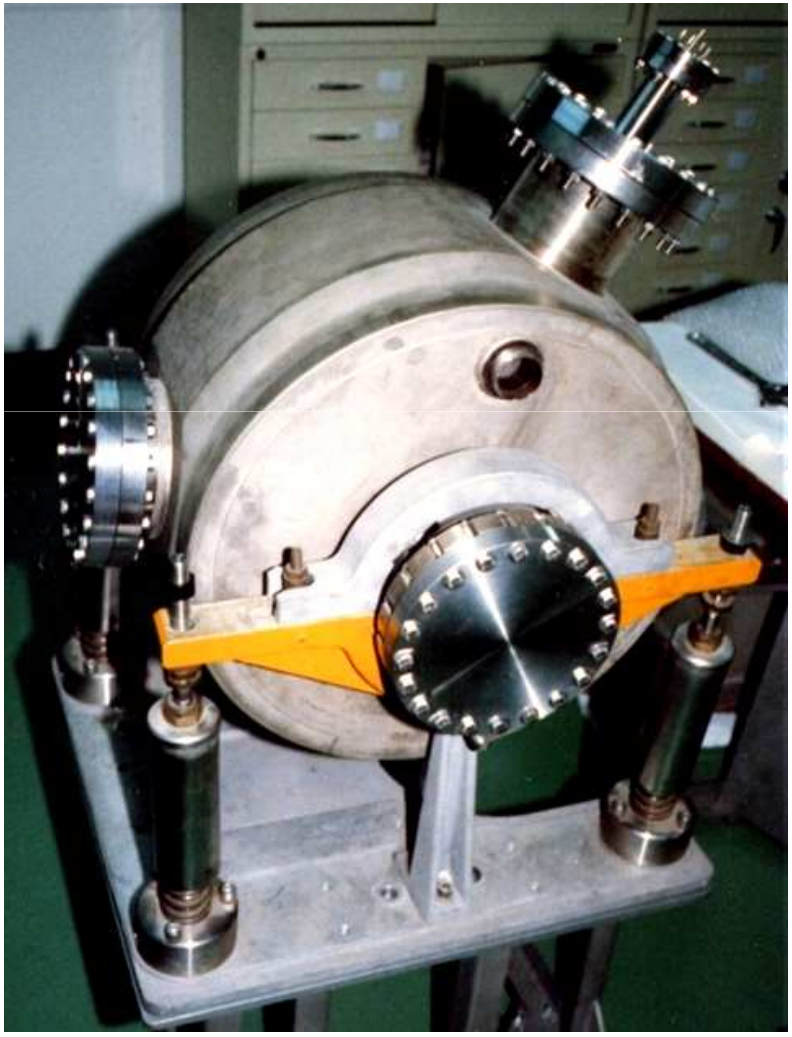
加速環

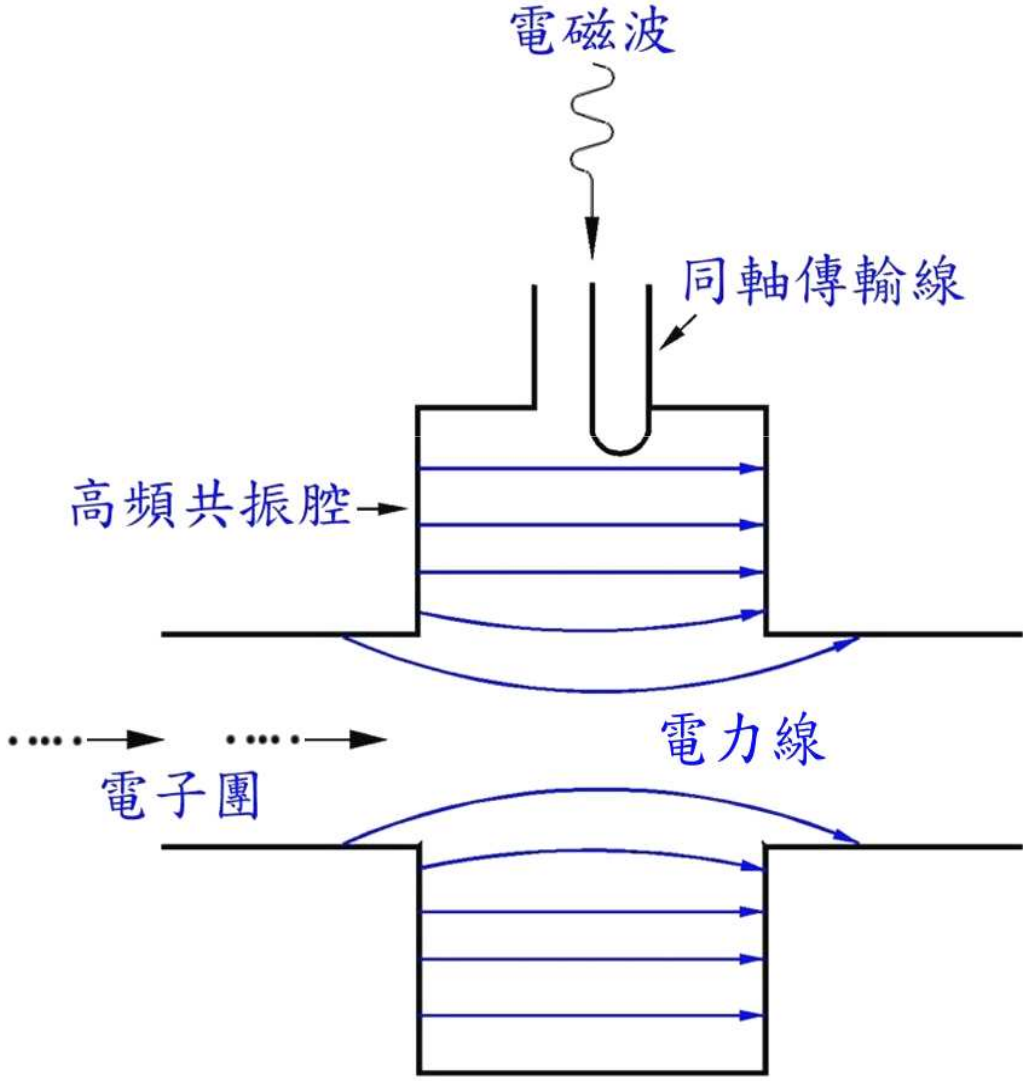


儲存環週邊的實驗設備



500 MHz 高頻共振腔





高頻系統

60 kW速調管

高頻控制系統

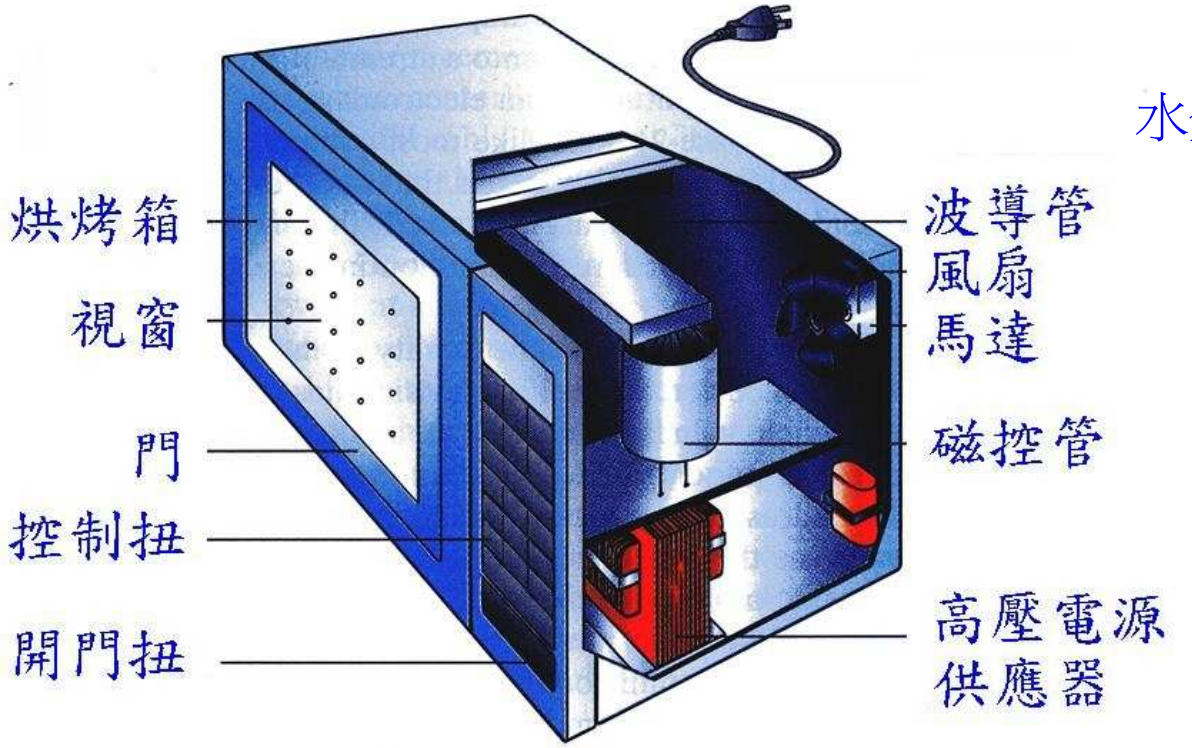
電源供應器

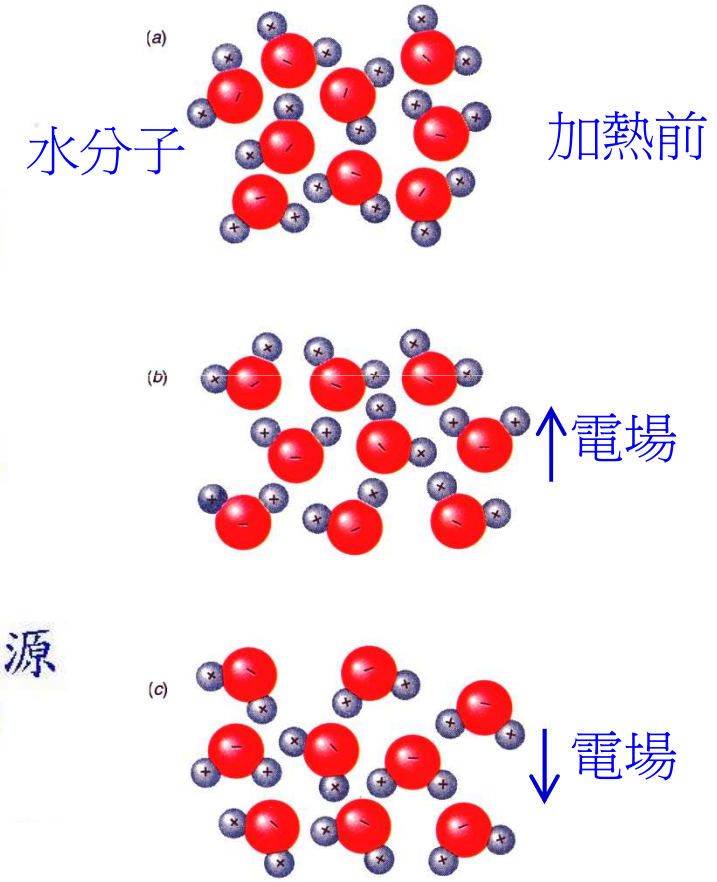
同軸傳輸線

冷卻系統

微波循環器

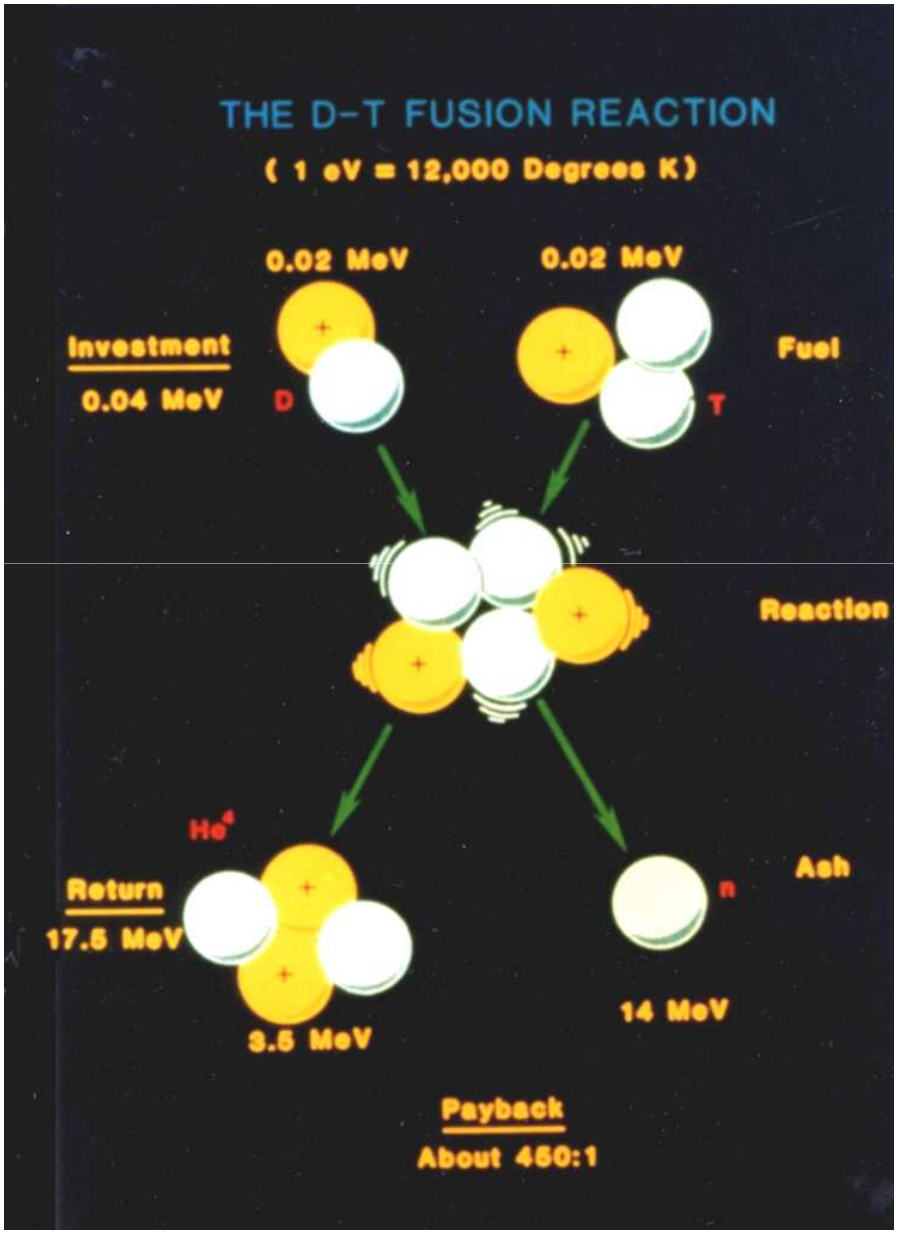
微波爐



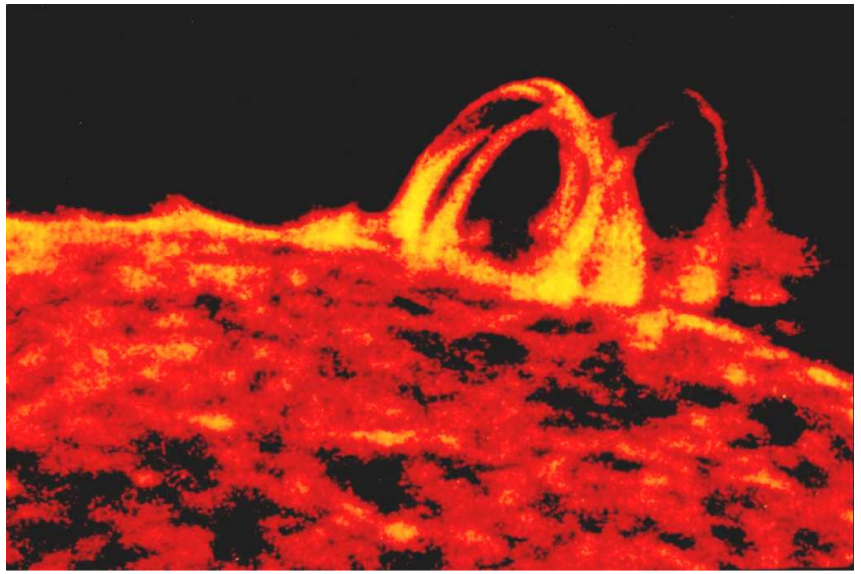


(取材自L. A. Bloomfield, “How Things Work”)

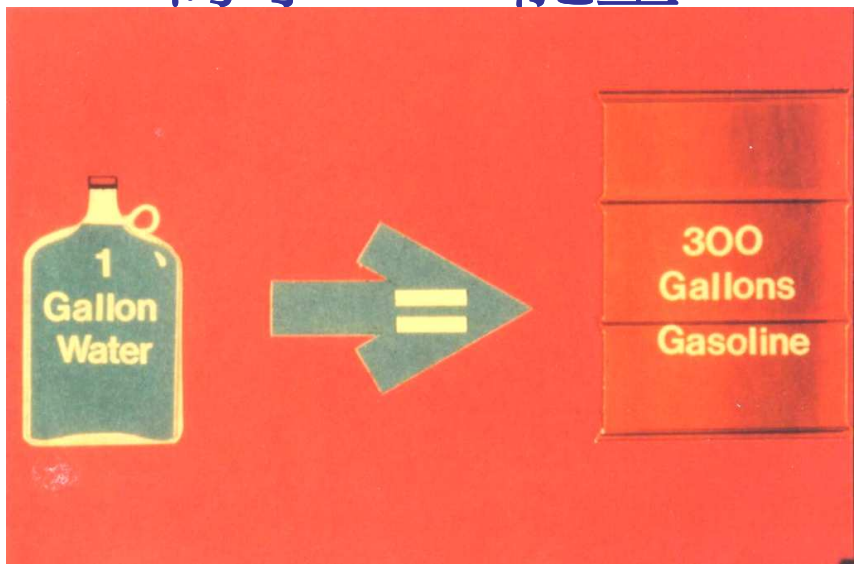
核融合反應



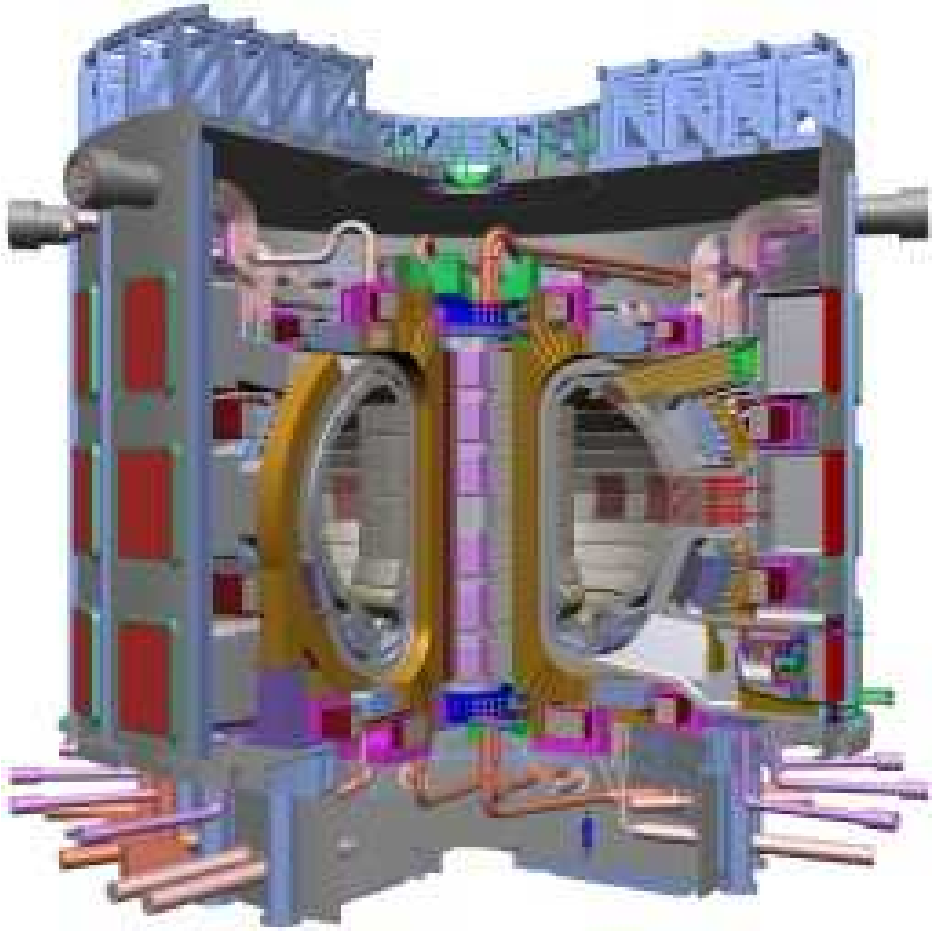
天然的核融合爐：太陽



海水 ⟶ 能量



國際核融合實驗反應爐: ITER
(International Thermonuclear Experimental Reactor)



合作國家： 歐盟、美、俄、日、中、韓

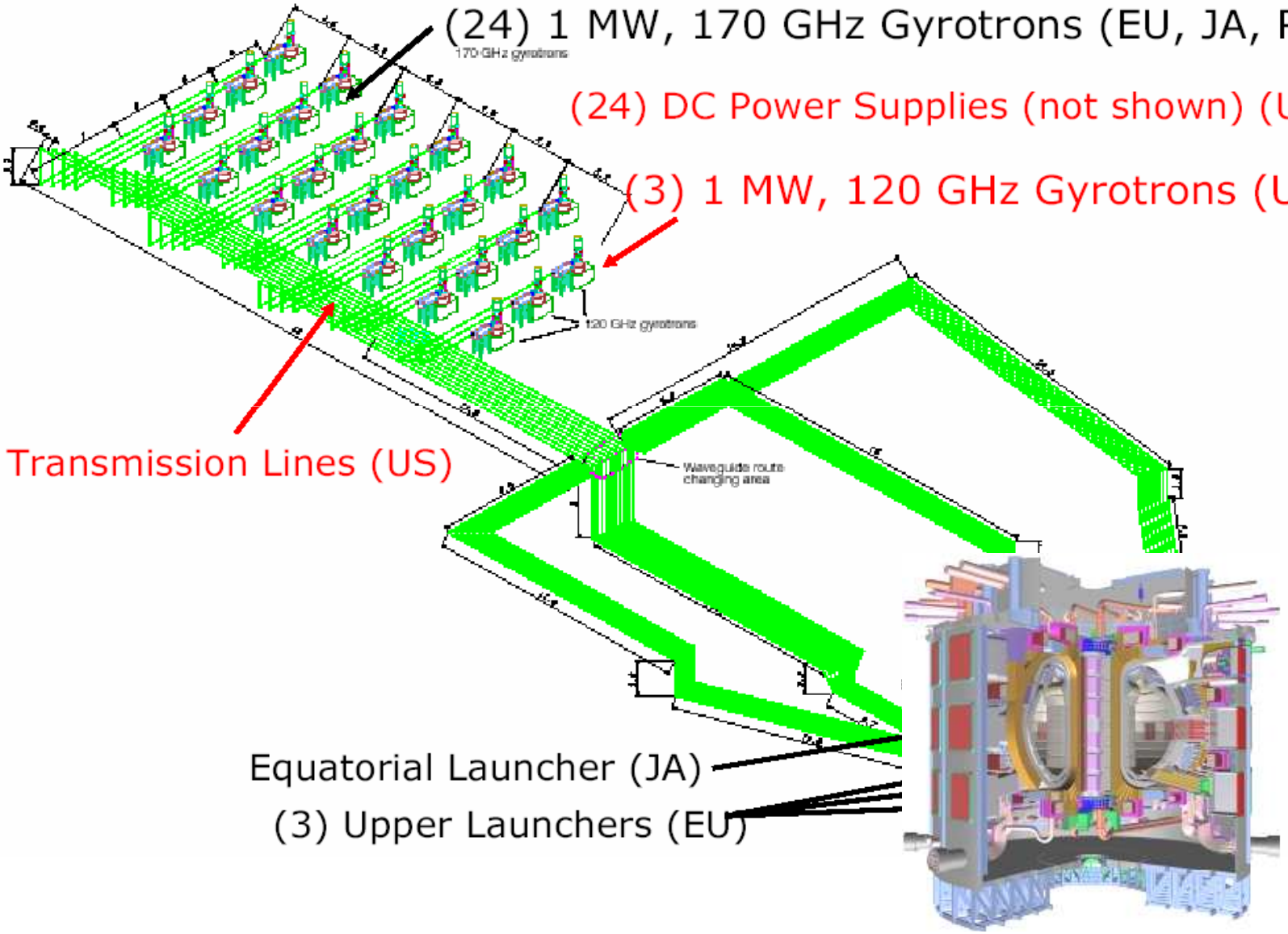
預算：150億美元

預期完工日期：2015年

電漿溫度：攝氏1億度

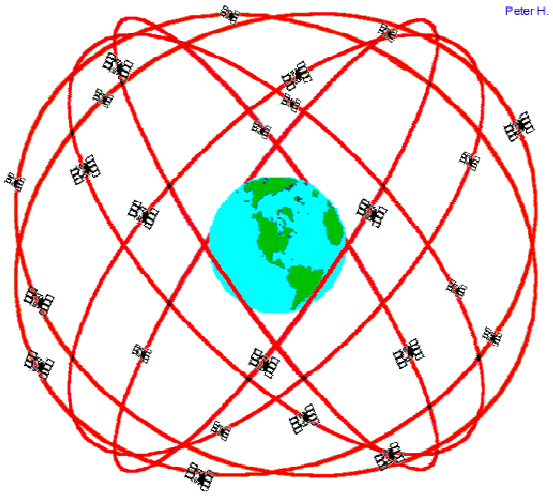
預期產生功率：500 MW

ITER的微波加熱系統



* R. Vernon *et al.*, in the 16th ANS Meeting on the Technology of Fusion Energy, Madison, Wisconsin, 2004

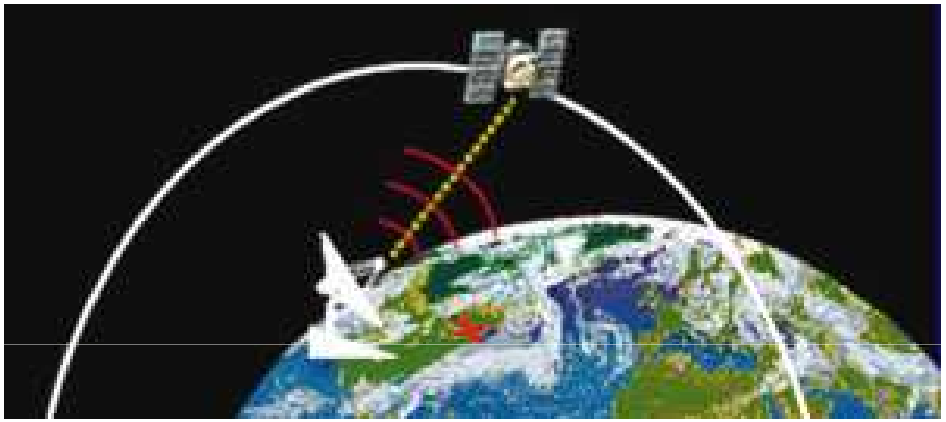
衛星定位系統
(GPS，Global Positioning System)



- 共24顆，圓形軌道，高度約2万公里，每12小時繞地球一週。任何地方，都可同時觀測到4顆以上的衛星。
- 使用1.58 GHz (L1 signal)及1.23 GHz (L2 signal)兩個頻率。

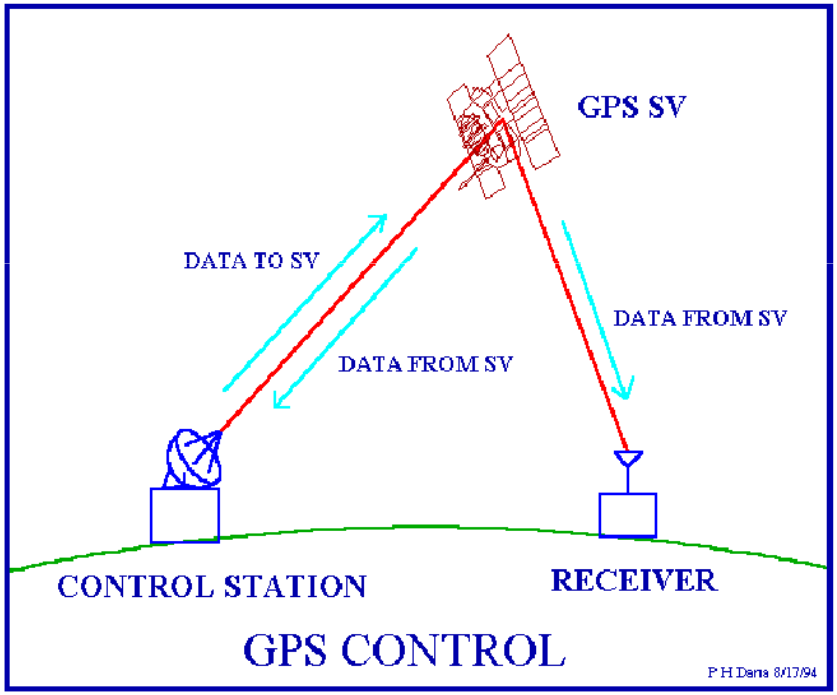
- 美國耗資約120億美元，歷時20年，於1994年完成。
- 可測量任何物體的三维座標、運動軌道和速度。

如何確定衛星的位置
— 軌道計算+雷達測量修正

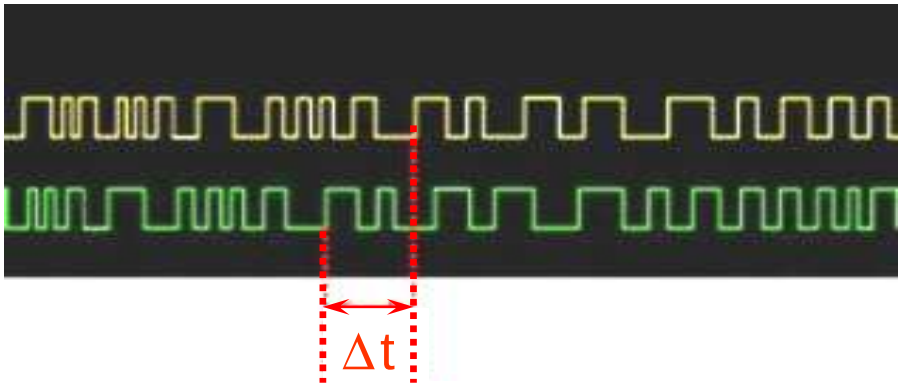


(取材自Trimble Navigation)

Global Positioning System (GPS) Master Control and Monitor Station Network



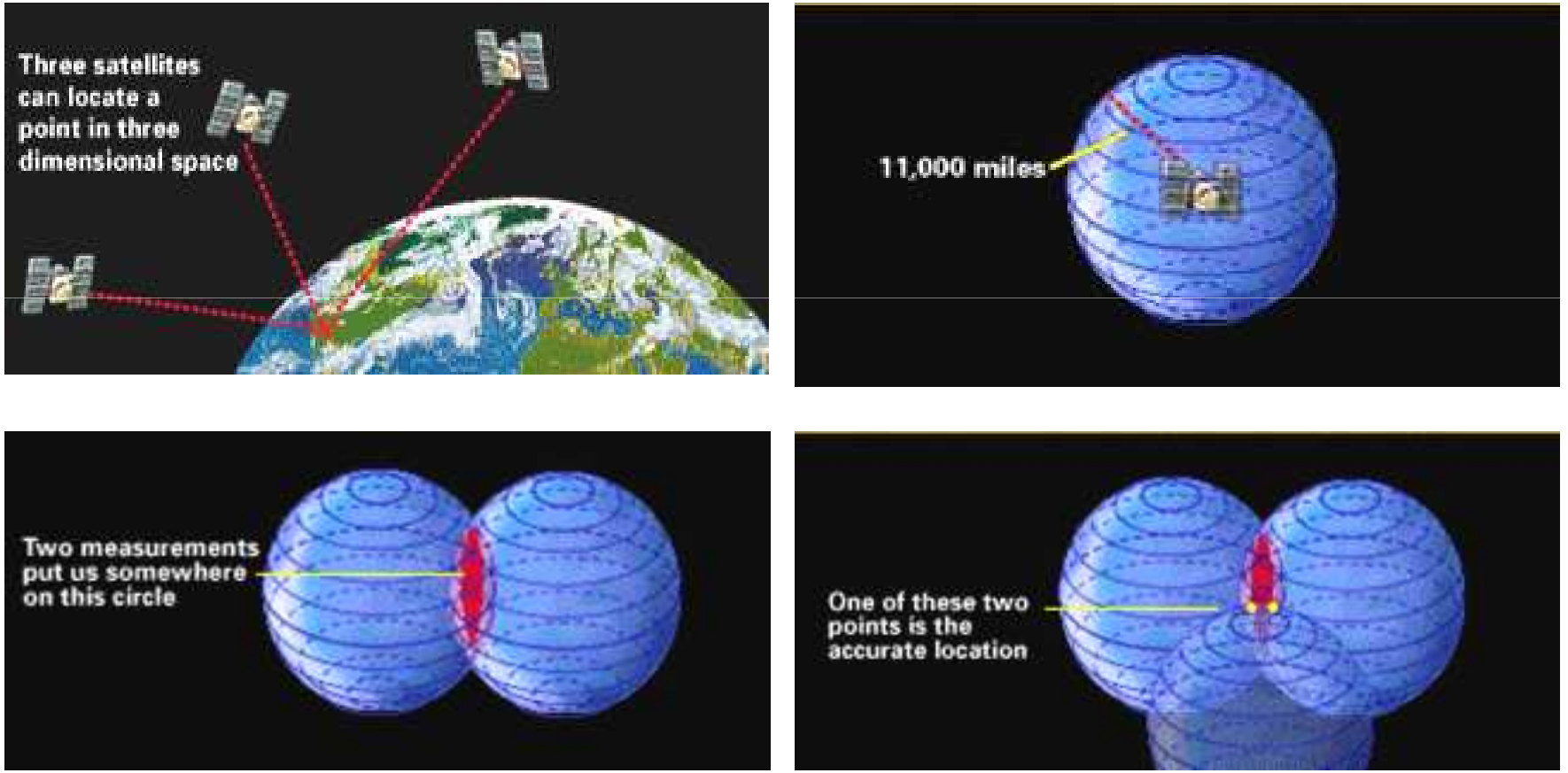
如何測量接收機和衛星的距離
— 時差×光速



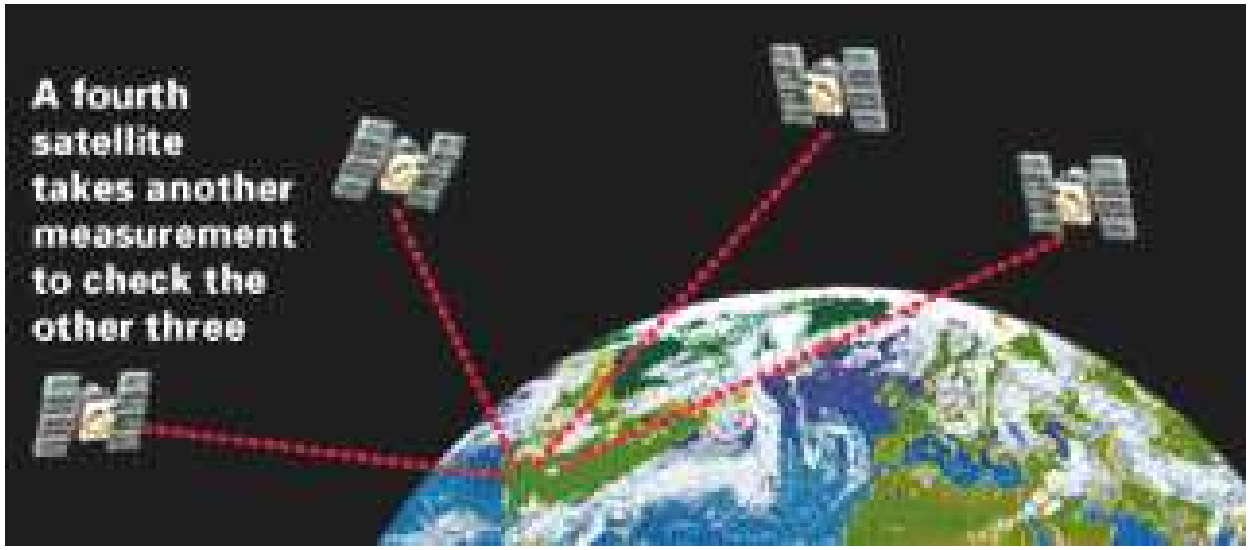
(取材自Trimble Navigation)

每顆衛星每毫秒送出一個該衛星特有的編碼訊號。接收機也同步產生相同的訊號，與衛星訊號到達時間比對後，其時差乘以光速即爲接收機與衛星的距離。

如何測量接收機的位置
—利用三角測量原理



(取材自Trimble Navigation)



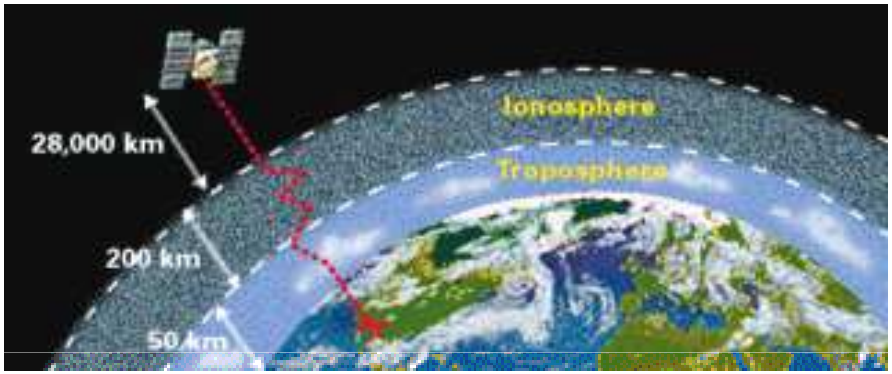
(取材自Trimble Navigation)

第四顆衛星確定接收機的位置，並修正接收機上的時鐘誤差。

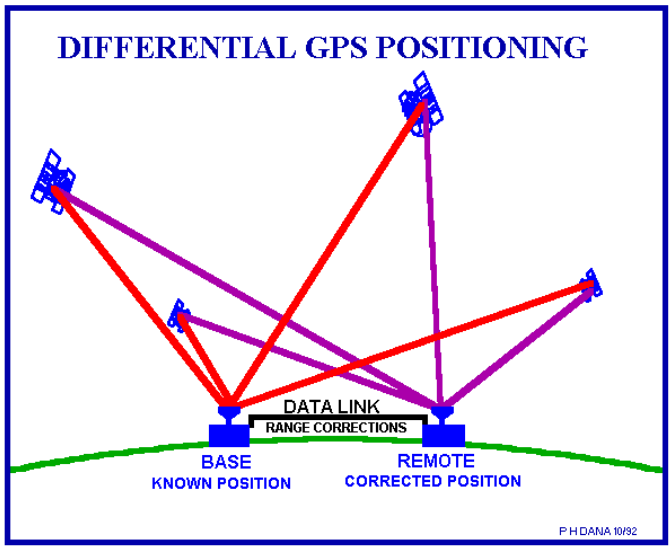
(衛星上有精確的原子鐘，接收機上只有一般的電子鐘)

如何修正訊號在大氣中的延誤

－設置參考接收站



(取材自Trimble Navigation)



參考站之座標位置爲已知，其上之接收機，可算出衛星訊號抵達所延誤的時間，立即傳給鄰近的接收機，或留作日後修正使用。

謝謝