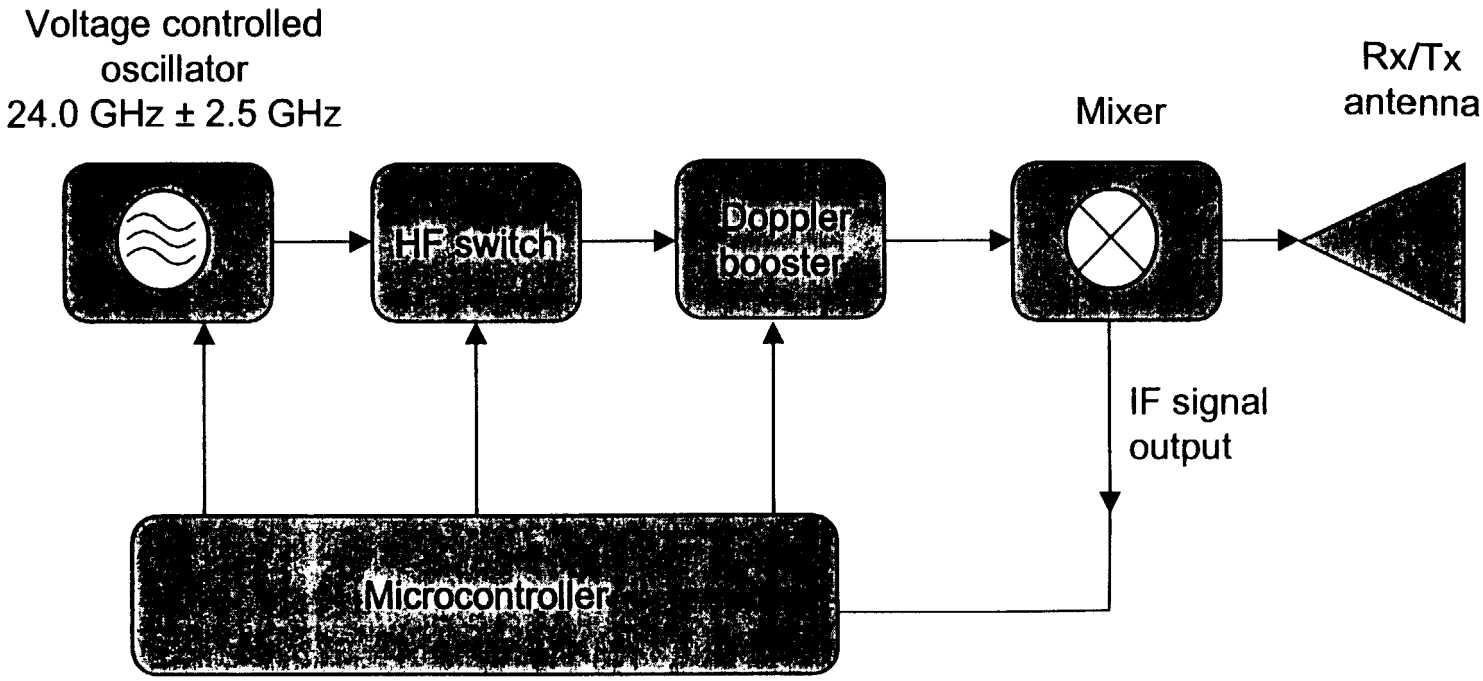
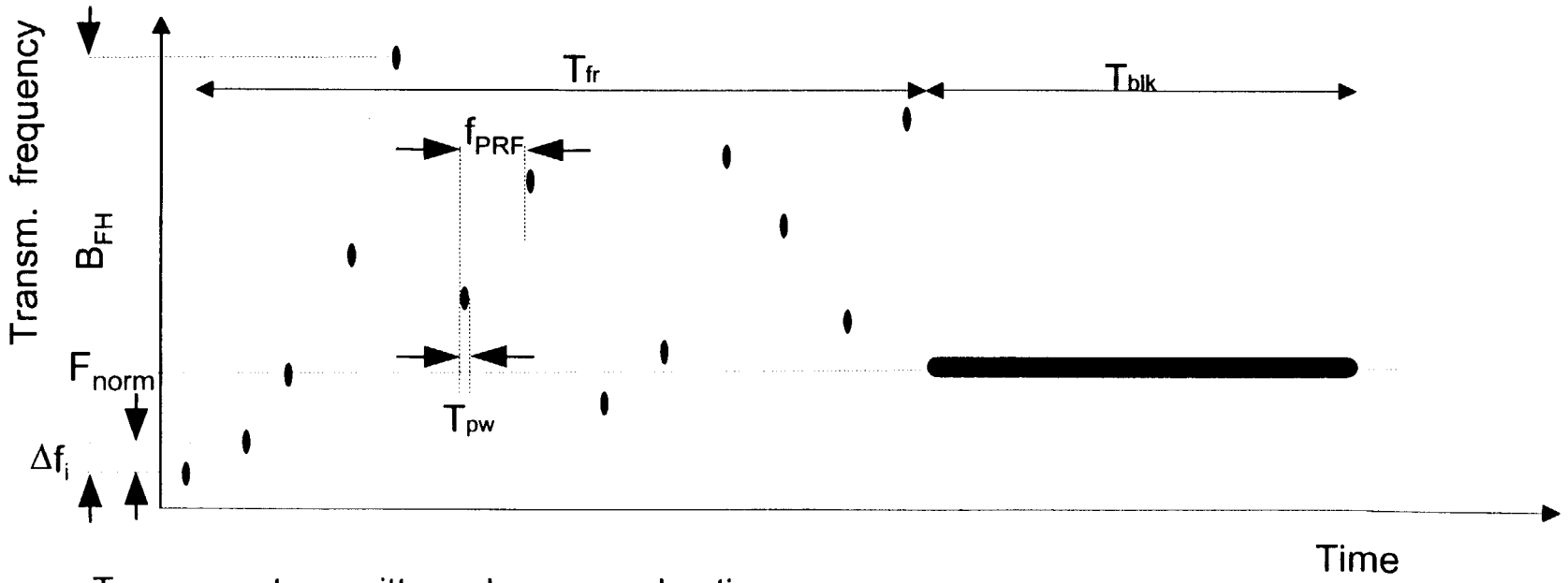
Basic functional diagram of pulsed FH radar:



Microcontroller controls VCO span, HF pulse, duty cycle and Doppler Booster amplification

Typical pulsed FH modulation form with parameter definitions :



T_{pw}:	transmitter pulse power duration
f_{PRF}:	Pulse repetition frequency
Δf_i:	hopping channel carrier frequency separation
T_{fr}:	Frame time period
T_{blk}:	Blanking period (for Doppler measurement)
F_{norm}:	Nominal operating frequency for fixed carrier (Doppler measurement)
B_{FH}:	Occupied bandwidth (DSB $_{-10\ dB}$) with $n * \Delta f_i = B_{FH}$

Audi, BMW, DaimlerChrysler, Fiat, Ford, Jaguar, Opel / GM, Porsche, PSA Peugeot Citroën, Renault, Saab, Seat, Volkswagen, Volvo, A.D.C., Bosch, Delphi, InnoSent, Megamos, Siemens VDO, TRW, Tyco Electronics, Valeo, Visteon.

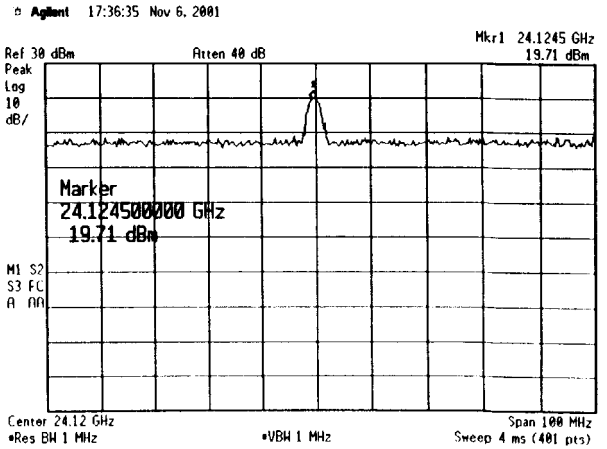
Siemens VDO 24 GHz NDS Radar characteristics:

PARAMETER	DEF	MIN	TYP	MAX	UNIT	REMARKS
Operating Characteristics						
Nominal operating frequency	F_{norm}	24.075	24.125	24.175	GHz	For Doppler in ISM Band
Frequency hopping bandwidth	B_{FHSS}	1	2	5	GHz	symmetrical or asymmetrical around F_{norm}
Avg. power EIRP	P_{AVG}	-40		20	dBm	depends on operational mode (Doppler,narrowband or B_{FH})
Peak power EIRP	P_{PK}	-10		20	dBm	depends on operational mode (Doppler,narrowband or B_{FH})
Power Spectral Density Mean	PSD_{mean}			-101.25	dBm/Hz	500 µV/m according to 47 CFR § 15.209
Power Spectral Density Peak	PSD_{peak}			-81.25	dBm/Hz	within B_{FH} @50 MHz RBW
Pulse Width	T_{pw}	5		300	ns	
Duty Factor	k_{duty}	0/13		30	dB	FH spreading not included 0 for Doppler in ISM Band
Pulse Repetition Frequency	f_{PRF}	10		1000	kHz	
Frame time period	T_{fr}	2	5	20	ms	
Blanking time period	T_{blk}	0		10	ms	used for ISM fixed carrier F_{norm} Doppler measurement
hopping channel carrier frequency separation	Δf_i	1	10	50	MHz	
Antenna Characteristics						
Vertical Beamwidth	φ_{10dB}		30		deg	-10 dB points
Vertical Beam Offset	$\Delta\varphi$		0		deg	from beam center boresight
Horizontal Beamwidth	ϑ_{10dB}		80		deg	-10 dB points
Horizontal Beam Offset	$\Delta\vartheta$		0		deg	from beam center boresight
Sidelobe attenuation	P_{ss}		20		dB	
Polarisation						Linear

Different operation mode examples:

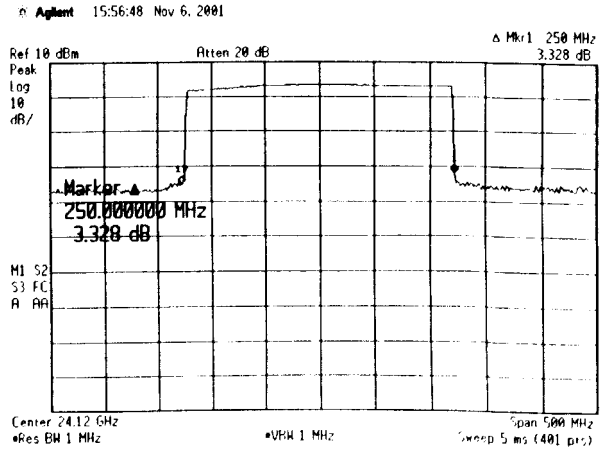
a) Simple Doppler evaluation:

- VCO fixed at constant carrier frequency at 24.125 GHz ± 50 MHz
- HF switch continuously closed
- Doppler booster on
- no spectral spread of carrier
- $P_{avg} = P_{PK}$ = 558,4 mV/m @ 3m = 19.71 dBm/MHz (below 47 CFR §15.245 limits)



b) Low resolution, far range measurement:

- VCO with carrier frequency modulation between 24.0 GHz to 24.25GHz
- HF switch with low duty cycle
- Doppler booster on
- P_{PK} = 91.5 mV/m @ 3m = 4 dBm/MHz (below 47 CFR §15.249 limits)

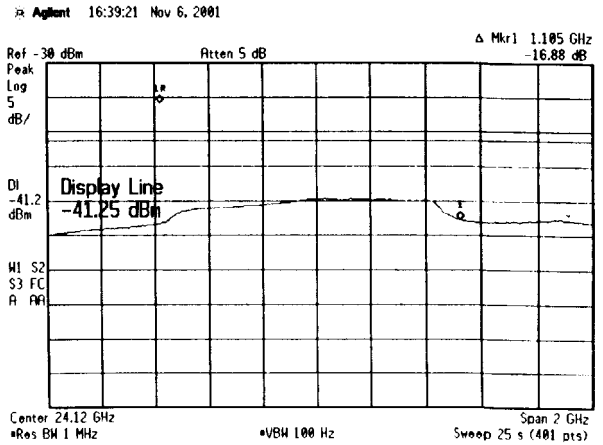


c) High resolution, short range measurement:

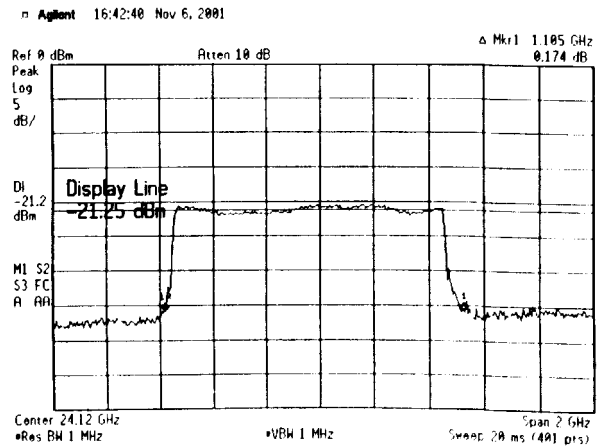
- VCO with carrier frequency modulation between 23.575 GHz to 24.575 GHz

- HF switch with short pulse and high duty cycle
- Doppler booster off

- wide spectral spread of carrier (UWB)



upper image (average power):
- P_{avg} = 182,6 µV/m @ 3m = -50 dBm/MHz
(below 47 CFR §15.209 limits)



lower image (peak power):
- P_{PK} = 5000 µV/m @ 3m = -21.25 dBm/MHz
(below 47 CFR §15.35 (b) limits)

Siemens VDO 24 GHz NDS Radar - Conclusions

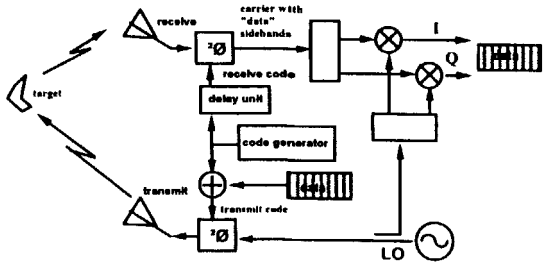
- The high resolution requirements for near distance automotive applications requires frequency bandwidth in excess of 1 GHz
- For the pulsed FH radar the same emission limits (peak power, average power, etc.) as for pulsed UWB systems should apply
- Pulsed FH systems achieve similar Power Spectral Densities as UWB systems with a Peak Power EIRP below 0 dBm
- The overall duty cycle of pulsed FH can be in excess of 30 dB, resulting in very low mean power values. Thus absolute limits for peak power should be applied.

DELPHI
Automotive Systems

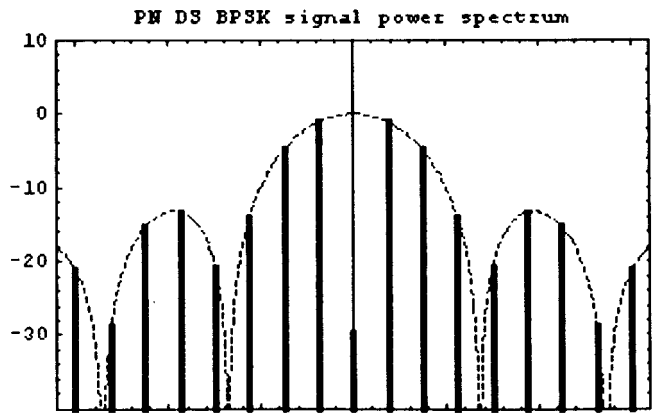
FCC OET visit Nov.13th, 2001
24 GHz Short Range Radar

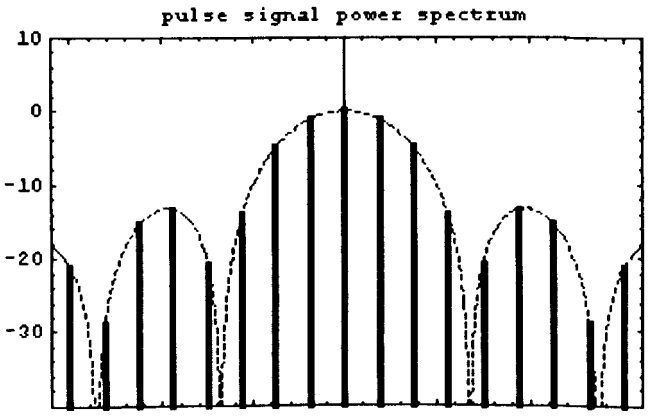
SARA

- Delphi has developed a unique low cost 24 GHz Double Side-band Pseudo Noise Bi-Phase Shift Keyed (DS-PN-BPSK) waveform radar sensor
- In the Frequency Domain this particular waveform has noise like properties and is almost indistinguishable from a classical pulse waveform



US Patent 5,731,781





Side by side detailed view of both pulse and PN direct sequence bi-phase shift key signal spectra. The frequency axis is in MHz away from the RF carrier. The difference between the two lies only in the spectral line amplitude at the RF carrier frequency. The pulse repetition frequency in the pulse waveform and the code repetition frequency in the PN DS BPSK waveform are equal, as are the pulse width and chip width.

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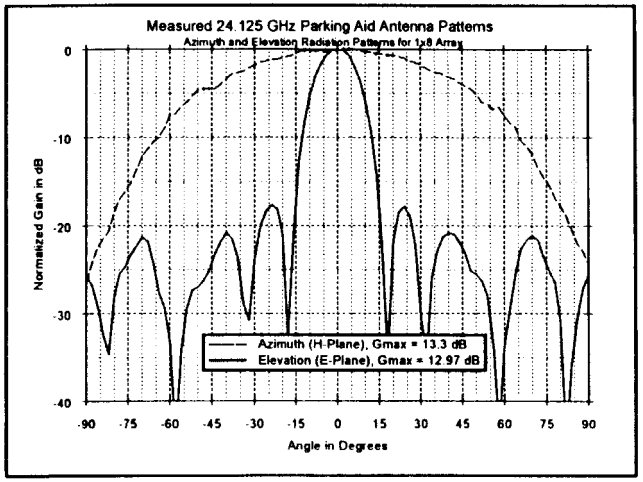
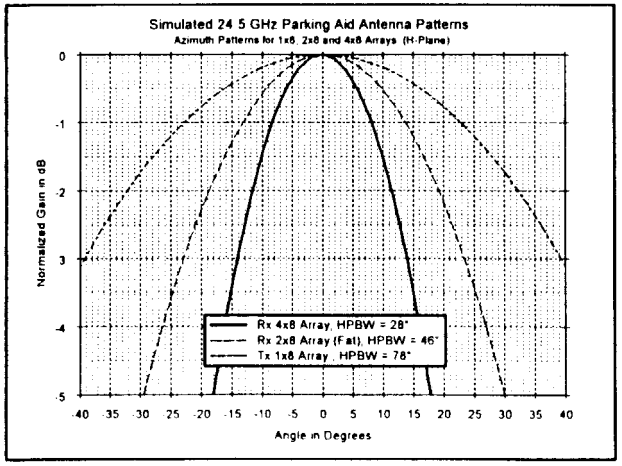
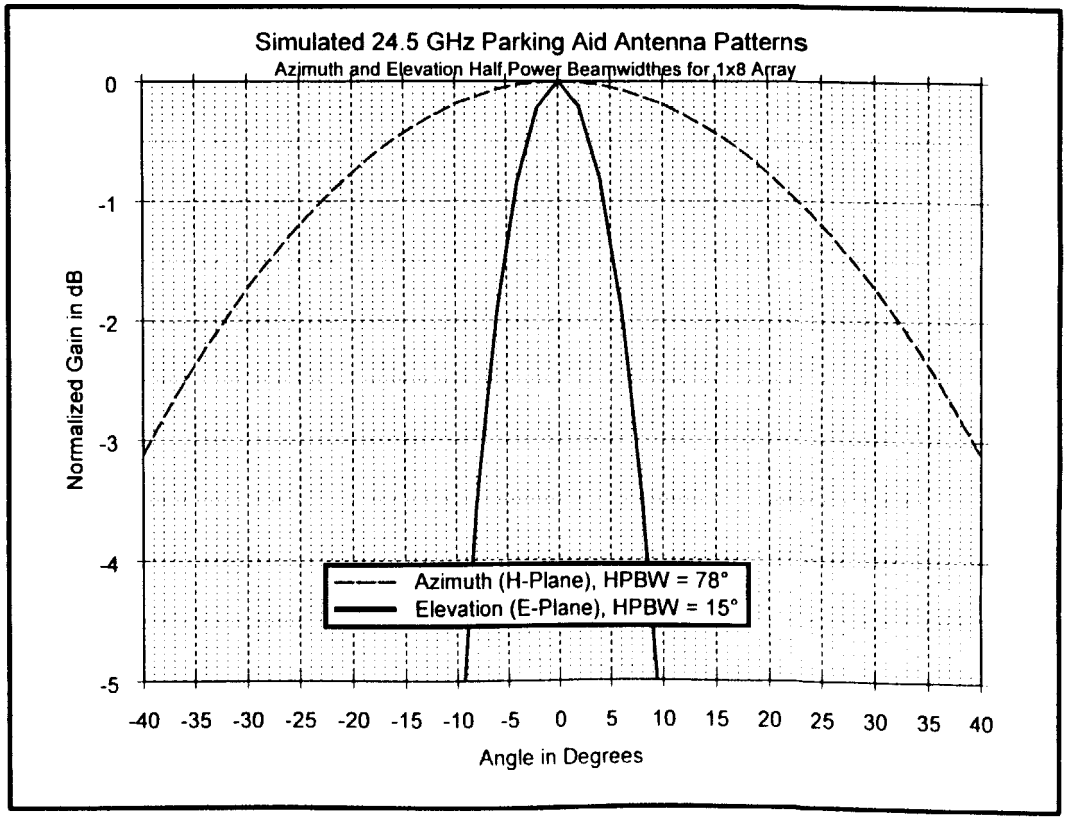
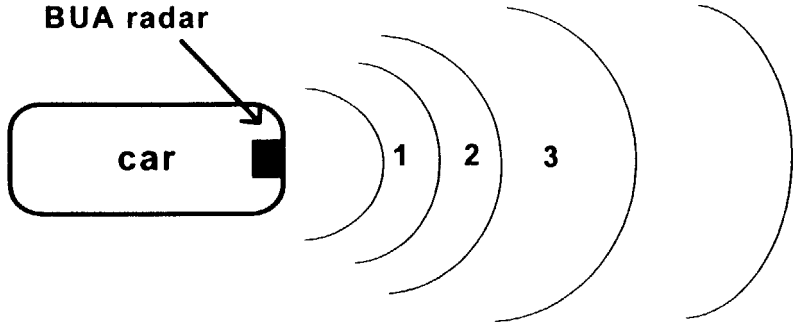




- Multiple element antenna pattern limits elevation radiation



- Wideband and narrower band emissions are needed for the various automotive safety applications. In some applications, overall performance is improved with narrower band emissions
- A narrower band system sequentially positions its single range bin to cover the entire desired area to the automobile rear. Using a variable width range bin vs. bin position preserves both response time and range data accuracy where needed.



- Longer duration chip widths (narrower bandwidth main lobe spectrum) emit lower average power in a 1 MHz bandwidth than very short duration chip width

BPSK RF Characteristics

	24 GHz B-PSK	Remarks
Range (RCS 1m^2)	8m	
Accuracy	+/- 5 cm	
Target Separation	22 cm	
Mean PSD	-116 dBm/Hz EIRP	Total radiated power divided by null to null bandwidth in dBm/Hz
Pulse Length	N/A	
Carrier Frequency	24.125	
Frequency Chirp/Carrier	N/A	
Phase modulated chip rate	375 MHz 750 MHz 1500 MHz	Changeable on the fly
-10 dB Bandwidth	550 MHz 1100 MHz 2200 MHz	(375 MHz Chip Rate) (750 MHz Chip Rate) (1500 MHz Chip Rate)
Peak envelope power over all spectrum	-21 dBm EIRP	
Time averaged power over all spectrum	-21 dBm EIRP	in 100 msec
Cycle Time	100 msec	

- Parameters beneficial to Delphi's sensor needs:
  - Approve wide bandwidth for automotive radar applications
  - Allow use of multiple waveforms so as to maximize system performance and supplier flexibility
  - The minimum recommendation is 500 MHz BW

- 24 GHz is a frequency that solves the implementation problems, including cost, performance, size, as well as positioning and mounting limitations in the car body....