Approach to Radar Detection Range Estimation

AN/APG-63, AN/APG-65 and AN/APG-73

Our AN/APG-65 and AN/APG-73 detection ranges estimation is based on public AN/APG-63 radar data[1], [2] and general radar theory considerations. According to [1], AN/APG-63 HPRF RWS mode has averaged detection range of 9 sqm RCS (frontal RCS of T-33 aircraft) target at approximately 63nm and approximately a 25nm detection range in MPRF mode against a 6 sqm RCS (averaged rear RCS of T-33 aircraft) target. General technical information for all three radars is summarized in the table below.

Parameter/Radar	AN/APG-63	AN/APG-65	AN/APG-73
Antenna type and diameter	Planar slotted array 0.915m (36")[1]	Planar slotted array 0.675m (26")	Planar slotted array 0.675m (26")[3]
Prime power	10kw	8kw	9kw
Transmitter input power	No data	4.5kw	4.5kw[3]
HPRF average power	No data	Assume same as APG-63	as APG-65 has
MPRF average power	No data	Assume same as APG-63	as APG-65 has
Noise figure	4-6dB	4-6dB	Reduced by 1-2dB
ADC amplitude bits	8[2]	11	11[3]
ADC sampling rate	No data	No data	Increased, 5MHz
MPRF pulse compression	Barker-13[2]	Barker-13	Barker-13[3]
HPRF FFT points	512[2]	1024	2048[3]
MPRF FFT points	16(10 used)[2]	No data	No data
MPRF range bins	64[2]	No data	No data
HPRF detection range	54nm[1]	51nm*	65nm*
MPRF detection range	24nm[1]	23nm*	30nm*

Note: all detection ranges in the table assume a target with a 5sqm RCS; star-marked ranges – our estimation, that will be explained below; items without reference/not marked– our assumption.

For further explanations we will need the radar equation, so here it is:

$$R_{p_d} = \left[\frac{P_{avg} A_e^2 \sigma t_{ot}}{(4\pi)^2 (S/N)_{req} kT_s \lambda^2 L} \right]^{1/4}$$

Pavg – average transmitter power
Ae – effective antenna area, Ae = n * PI * d^2/4, d – antenna diameter, n – aperture efficiency
σ - target RCS
tot - time on target(dwell time)
L – losses (all kinds)
λ – radar wavelength
kTs – mean noise energy
(S/N)req – signal-to-noise ratio for requested detection probability
Rpd – range at which required detection probability is achieved

First of all, this equation contains several parameters with unknown values (Pavg, (S/N)req, and L) and has impacted our approach. Instead of best estimating these missing values, we decided to focus on parameter ratios. All three radars were developed by the same company, have a similar, general design, and have similar signal processing. Therefore, we judge that such an approach will provide good results.

The average transmitted power is unknown for both the AN/APG-63 and the AN/APG-65(73); however, based on radar dimensions and assumed power consumption, these radars should have very similar Pavg. Even if we suppose a 1.5x difference in power, reasonable differences in detection range will be $\sqrt[4]{1.5}$ = 1.106. In other words, detection range will differ by less than 11%. So, in our estimation, Pavg assumed to be equal.

Target RCS σ should be a constant reference value to make any comparison/estimation possible. For convenience, detection ranges from [1] were recalculated for RCS of 5 sqm. That is 63 nm * $\sqrt[4]{5/9}$ = 54nm and 25 nm * $\sqrt[4]{5/6}$ = 24nm.

The next parameter is the effective antenna area, Ae. According to the radar equation, detection range is proportional to the square root of Ae (second power x ¼ power = ½ power). Ae is itself proportional to antenna diameter squared, so detection range is directly proportional to antenna diameter. Thus, we have 54nm * 0.675/0.915 = 40 nm. However, our radars are scanning ones, and we must account for the difference in beamwidth because it affects time on target that is also included in the radar equation.

Beamwidth is inversely proportional to antenna diameter (we assume that wavelength is the same), and hence the tot as well. That gives us 40 nm * $\sqrt[4]{0.915/0.675}$ = 43nm. Time on target also depends on the average scan rate, but these radars have approximately the same scan rate, so, we do not take this possible difference into account due to how minor it is.

The signal-to-noise ratio, SNR, and L losses are the most complicated parameters because each of them combines several distinct sources of noise and losses. Unfortunately, there is little information about radar components and DSP features of modern radar, so estimation will account for only known data. Other parameters assumed unchanged or moderately changed.

The AN/APG-65(73) has 2x better doppler resolution than the AN/APG-63, increased analog-to-digital converter amplitude resolution, and other changes. This may imply 2x better SNR. Let's account for this as 43 nm * $\sqrt[4]{2}$ = 51nm. This is our final detection range for HPRF RWS mode of the AN/APG-65 radar.

AN/APG-65 MPRF mode uses 13:1 Braker code pulse compression, like the AN/APG-63. However, actual range-doppler resolution is unknown. Assuming the same level of resolution improvement over the AN/APG-63 as in HPRF mode, we can however expect the same ratio between HPRF and MPRF detection ranges as the AN/APG-63. So here is our AN/APG-65 MPRF detection range 51nm *24/54 = 23nm.

The AN/APG-73 is an upgraded version of AN/APG-65. According to public information, the AN/ APG-73 uses the same antenna and the same traveling wave tube transmitter as the APG-65, but it received a new data processor, power supply, and receiver/exciter. From this we can conclude that at least the receiver noise figure was improved. Since both AN/APG-63 and AN/APG-65 receivers were equipped with low-noise amplifiers, we can expect a moderate improvement of 1-2dB. This gives us an HPRF RWS detection range of around 51nm * $\sqrt[4]{10^{1.5/10}}$ = 55nm and 23nm * $\sqrt[4]{10^{1.5/10}}$ = 25nm detection range in MPRF mode. Taking this into account, increasing throughput of the data processor and 2x better doppler resolution we can expect additional SNR improvement via more intense DSP. Will assume it another 2x improvement, 55 nm * $\sqrt[4]{2}$ = 65nm and 25 nm * $\sqrt[4]{2}$ = 30nm. This is our final detection ranges of AN/APG-73.

References

1. F-15 design approach presentation http://aviationarchives.blogspot.com/2016/06/f-15-design-approach-presentation.html
2. Introduction To Airborne Radar, G.W. Stimson, 1st edition.
3. Introduction To Airborne Radar, G.W. Stimson, 2nd edition.