[VA] SRC#004- Fun with Sexagesimal Trigs

02-11-2019, 06:13 PM **Post: #1**

Valentin Albillo
Senior Member

Posts: 347
Joined: Feb 2015
Warning Level: 0%

[VA] SRC#004- Fun with Sexagesimal Trigs

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Hi, all:

Welcome to my brand new **SRC#004**, this time commemorating that this is my **300th** post here so if I'm not mistaken I'll be granted the description *"Senior Member"* from now on. What a treat !

Tired of trigs in *radians* ? Wanna see some trigs in *sexagesimal degrees* ? Read on !

Details:

If you're in the mood for a nice helping of awesome *"sexagesimal"* results go and try your hand at *accurately* **evaluating** the following trig expressions, either manually or else by writing a short bit of **RPN**/**RPL**/**71BASIC**/**HPPL** code for your preferred **HP** calculator *(**not** Excel, Matlab, Mathematica, Python, Java, Haskell, C/C++, Wolfram Alpha, etc., there are many other forums/threads for that)*, namely:

$$A = (\sqrt{3} + tan\ 1^o)\ (\sqrt{3} + tan\ 2^o) \ldots (\sqrt{3} + tan\ 29^o)$$

$$B = \frac{1}{sin\ 45^o\ sin\ 46^o} + \frac{1}{sin\ 47^o\ sin\ 48^o} + \ldots + \frac{1}{sin\ 133^o\ sin\ 134^o}$$

$$C = \left(1 - \frac{cos\ 61^o}{cos\ 1^o}\right) \left(1 - \frac{cos\ 62^o}{cos\ 2^o}\right) \ldots \left(1 - \frac{cos\ 119^o}{cos\ 59^o}\right)$$

$$D = \left(1 - \frac{1}{tan\ 1^o}\right) \left(1 - \frac{1}{tan\ 2^o}\right) \ldots \left(1 - \frac{1}{tan\ 44^o}\right)$$

$$E = \left(2\ cos\ 2^{2\circ} - \frac{1}{cos\ 2^{2\circ}}\right)\ \left(2\ cos\ 2^{3\circ} - \frac{1}{cos\ 2^{3\circ}}\right)\ \ldots\ \left(2\ cos\ 2^{25\circ} - \frac{1}{cos\ 2^{25\circ}}\right)$$

Once you've succeeded in accurately evaluating them you should attempt to **identify** the results that aren't immediately obvious (i.e.: if you get something like *1.7320508..* you should identify it as $\sqrt{3}$), which will be useful to gauge the accuracy obtained by comparing what you got with the exact results, *benchmark*-like.

You must *not* use anything other than your intuition and the help of your trusty HP calculator for the identification (in particular give the Internet a miss) but those of you using HP calcs with **CAS** might want to check if your CAS will produce the *exact* results at once or if at least it will simplify them to something much .. well, simpler !

Let's see your code, results and comments (try not to spoil early the fun for others), I will post mine within a few days.

V.
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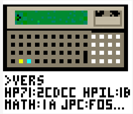
02-11-2019, 09:55 PM **Post: #2**



J-F Garnier
Senior Member

Posts: 302
Joined: Dec 2013

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

> **Valentin Albillo Wrote:** (02-11-2019 06:13 PM)
> You must *not* use anything other than your intuition and the help of your trusty HP calculator for the identification...

So the use of your great IDENTIFY program is perfectly legal ? :-)

J-F

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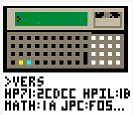
02-11-2019, 11:26 PM **Post: #3**



J-F Garnier
Senior Member

Posts: 302
Joined: Dec 2013

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

Amazing expressions !

Programming (especially on the 71) is immediate - no need to post it - , but the identification of the B value stopped me for a while.

J-F

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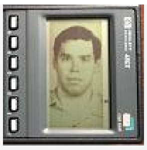
02-11-2019, 11:51 PM (This post was last modified: 02-12-2019 03:37 AM by Gerson W. Barbosa.) **Post: #4**

Gerson W. Barbosa

Posts: 1,135
Joined: Dec 2013



Senior Member

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

> **J-F Garnier Wrote:** ⇒ (02-11-2019 11:26 PM)
>
> Amazing expressions !
>
> Programming (especially on the 71) is immediate - no need to post it -

Agreed. Same on the 50g.

Gerson.

PS.: Not a spoiler, just a reminder to myself...

ALBINVASINCDLBE++++->51.9999999999

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02-12-2019, 05:37 AM (This post was last modified: 02-14-2019 04:39 AM by Albert Chan.) **Post: #5**

Albert Chan
Senior Member

Posts: 624
Joined: Jul 2018

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

> **J-F Garnier Wrote:** ⇒ (02-11-2019 11:26 PM)
>
> the identification of the B value stopped me for a while.

Here is a good way to estimate B.

Middle term angle is around 90°, any angles bigger than that can be used to fill the "holes":

Example, 1/(sin(133°)sin(134°)) = 1/(sin(47°)sin(46°))

So, B = 1/(sin(45°)sin(46°)) + 1/(sin(46°)sin(47°)) + ... + 1/(sin(89°)sin(90°))

I remember derivative of tan(x) is sec(x)^2 = 1/cos(x)^2

So, change all the sines to cosines, angles goes from 0° to 45°
The x's are in degree, so need to scale the area, like this:

sum ~ (180/Pi) * integrate(sec(x)^2, x, 0, Pi/4) = (180/Pi) * (1 - 0) = 180/Pi

Actual sum is not exactly like this, but should be close.
My guess for true sum is 1/sin(1°), but to prove it is hard ...

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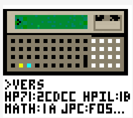
02-12-2019, 10:05 AM (This post was last modified: 02-12-2019 10:37 AM by J-F Garnier.) **Post: #6**



J-F Garnier
Senior Member

Posts: 302
Joined: Dec 2013

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

> **J-F Garnier Wrote:** (02-11-2019 11:26 PM)
>
> Programming (especially on the 71) is immediate - no need to post it -

Well, *straightforward* programming is indeed immediate and enough to get an idea of the results, but it is possible to do slightly better "in *accurately* evaluating them"

Let's see on value A.
Straightforward programming:
>A=1 @ FOR I=1 TO 29 @ A=A*(SQR(3)+TAN(I)) @ NEXT I @ DISP A
536870912.011

The rounding error on SQR(3), accumulated on 29 successive iterations introduces a systematic bias.
We can reduce this effect by factoring SQR(3) and evaluating SQR(3)^29 directly:
>A=1 @ FOR I=1 TO 29 @ A=A*(1+TAN(I)/SQR(3)) @ NEXT I @ A=A*3^14*SQR(3) @ DISP A
536870912.002

This gives us more confidence in identifying it to a certain simple integer expression.

J-F

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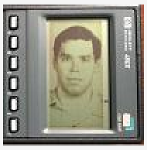
02-12-2019, 11:50 AM (This post was last modified: 02-12-2019 11:50 AM by Gerson W. Barbosa.) **Post: #7**



Gerson W. Barbosa
Senior Member

Posts: 1,135
Joined: Dec 2013

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

> **J-F Garnier Wrote:** (02-12-2019 10:05 AM)
>
> The rounding error on SQR(3), accumulated on 29 successive iterations introduces a systematic bias.
> We can reduce this effect by factoring SQR(3) and evaluating SQR(3)^29 directly:
> >A=1 @ FOR I=1 TO 29 @ A=A*(1+TAN(I)/SQR(3)) @ NEXT I @ A=A*3^14*SQR(3) @ DISP A
> 536870912.002
>
> This gives us more confidence in identifying it to a certain simple integer expression.

Right in between:

```
« 1 1 29
FOR i i DUP + SIN LASTARG COS 1 + / 3 √ + *
NEXT
»
```

EVAL ->

536870912.006

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02-12-2019, 02:14 PM **Post: #8**

Posts: 624

Albert Chan
Senior Member
Joined: Jul 2018

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

Prove A = 2^29 = 536870912:

Checking the edges, using shorthand t# = tan(#°):

tan(A°+B°) = (tA + tB) / (1 - tA tB)

(t60 + tA) (t60 + tB), where A+B=30°
= t60^2 + t60*(tA + tB) + tA tB
= t60^2 + t60*t30*(1 - tA tB) + tA tB
= 3 + 1 - tA tB + tA tB
= 2^2

t15 = tan(45° - 30°)
= (t45 - t30) / (1 + t45 t30)
= (1 - 1/√3) / (1 + 1/√3)
= (√3 - 1) / (√3 + 1)
= (√3 - 1)^2 / (3 - 1)
= (3 + 1 - 2*√3) / 2

-> t15 = 2 - √3
-> center = t60 + t15 = 2

14 pairs of edges and 1 center, all can considered value of 2, thus A = 2^29

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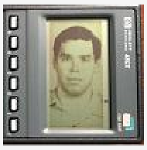
02-12-2019, 03:23 PM **Post: #9**



Gerson W. Barbosa
Senior Member
Posts: 1,135
Joined: Dec 2013

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

Albert Chan Wrote: (02-12-2019 02:14 PM)

Prove A = 2^29 = 536870912:

Checking the edges, using shorthand t# = tan(#°):

tan(A°+B°) = (tA + tB) / (1 - tA tB)

(t60 + tA) (t60 + tB), where A+B=30°
= t60^2 + t60*(tA + tB) + tA tB
= t60^2 + t60*t30*(1 - tA tB) + tA tB
= 3 + 1 - tA tB + tA tB
= 2^2

t15 = tan(45° - 30°)
= (t45 - t30) / (1 + t45 t30)
= (1 - 1/√3) / (1 + 1/√3)
= (√3 - 1) / (√3 + 1)
= (√3 - 1)^2 / (3 - 1)
= (3 + 1 - 2*√3) / 2

-> t15 = 2 - √3
-> center = t60 + t15 = 2

14 pairs of edges and 1 center, all can considered value of 2, thus A = 2^29

A is the only one I had trouble with because at first I had wrongly programmed it as a sum instead of a product. When I notice my mistake and finally got the correct value, I simply computed its base-2 logarithm in order to check it was a power of two. But only because I had identified D already. For whatever reason I decided to check the product of the first and last terms:

(1 - 1/tan1°)*(1 - 1/tan44°) = 1.99999999997

That's 2 to me, so I just did 2^22 = 4194304 which "matched" 4194303.99965, the value my D program returned, and I gave it no further thought.

I do appreciate, however, your efforts in going deeper into the problem and providing a proof.

Gerson.

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02-12-2019, 04:00 PM **Post: #10**

Albert Chan
Senior Member

Posts: 624
Joined: Jul 2018

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

J-F Garnier Wrote: (02-12-2019 10:05 AM)
We can reduce this effect by factoring SQR(3) and evaluating SQR(3)^29 directly:
>A=1 @ FOR I=1 TO 29 @ A=A*(1+TAN(I)/SQR(3)) @ NEXT I @ A=A*3^14*SQR(3) @ DISP A
536870912.002

3^14.5 may be more accurate than 3^14 * √ (3), avoided 1 rounding.
Example, on my HP-12C:

3 [Enter] 14.5 [X^Y] => 8,284,345.319
3 [Enter] 14 [X^Y] 3 [√X] x => 8,284,345.321

It may be more accurate to do corrections to A:

```
lua> function t(a) return math.tan(math.rad(a)) end
lua> sqrt3 = math.sqrt(3)

lua> a = 1
lua> for i=1,29 do a = a * (1 + t(i) / sqrt3) end
lua> a * 3^14.5
536870912.0000006

lua> a = 3^14.5
lua> for i=1,29 do a = a + a * t(i) / sqrt3 end
lua> a
536870912
```

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02-12-2019, 04:11 PM **Post: #11**

J-F Garnier
Senior Member

Posts: 302
Joined: Dec 2013

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

> **Albert Chan Wrote:** (02-12-2019 02:14 PM)
>
> Prove A = 2^29 = 536870912:
>
> Checking the edges, using shorthand t# = tan(#°):
>
> **tan(A°+B°) = (tA + tB) / (1 - tA tB)**
>
> (t60 + tA) (t60 + tB), where A+B=30°
> = t60^2 + t60*(tA + tB) + tA tB
> = t60^2 + t60*t30*(1 - tA tB) + tA tB
> = 3 + 1 - tA tB + tA tB
> = 2^2
>
> ...
>
> 14 pairs of edges and 1 center, all can considered value of 2, thus A = 2^29

Great!

With the same method (and notations), it's easy to prove D = 2^22:

tan(A°+B°) = (tA + tB) / (1 - tA tB)

(1 - 1/tA) (1 - 1/tB), where A+B=45°
= 1 - (1/tA + 1/tB) + 1/(tA tB)
= 1 - (tA + tB) / (tA tB) + 1 / (tA tB)
= 1 - t45 (1 - tA tB) / (tA tB) + 1 / (tA tB)
= 1 - (1 / (tA tB) - 1) + 1 / (tA tB)
= 2

J-F

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02-12-2019, 04:42 PM (This post was last modified: 02-12-2019 05:28 PM by Albert Chan.) **Post: #12**

Albert Chan
Senior Member

Posts: 624
Joined: Jul 2018

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

> **J-F Garnier Wrote:** (02-12-2019 04:11 PM)
>
> **tan(A°+B°) = (tA + tB) / (1 - tA tB)**
>
> (1 - 1/tA) (1 - 1/tB), where A+B=45°
> = 1 - (1/tA + 1/tB) + 1/(tA tB)
> = 1 - (tA + tB) / (tA tB) + 1 / (tA tB)
> = 1 - t45 (1 - tA tB) / (tA tB) + 1 / (tA tB)
> = 1 - (1 / (tA tB) - 1) + 1 / (tA tB)
> = 2

Neat! Perhaps this version is more elegant:

t45 = 1 = (tA + tB) / (1 - tA tB), where A+B=45°
-> **tA tB = 1 - tA - tB**

X = (1 - 1/tA) (1 - 1/tB)
tA tB X = (tA - 1) (tB - 1) = (tA tB + 1 - tA - tB) = 2 tA tB
X = 2

Bonus: For A+B=45°, we now have more accurate way to do 1 - tA - tB:

Example, on my Casio FX-115MS:
1 - t0.01 - t44.99 = 1.74472016000e-4 (with all internal digits)
1 - t44.99 - t0.01 = 1.74472015029e-4 (slightly better)
t0.01 * t44.99 = 1.74472014117e-4 (last digit should rounded to 8)

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02-12-2019, 06:39 PM (This post was last modified: 02-12-2019 06:41 PM by Albert Chan.) **Post: #13**

Albert Chan
Senior Member

Posts: 624
Joined: Jul 2018

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

Prove C = 1:

Using shorthand c(#) = c# = cos(#°), s(#) = s# = sin(#°)

C = (1 - c61/c1)(1 - c62/c2) ... (1 - c119/c59)

center = (1 + c90/c30) = (1 + 0/c30) = 1

Check the edges, each pair P had the form:
= (1 - c(90-x)/c(30-x)) * (1 - c(90+x)/c(30+x))
= (1 - sx / c(30-x)) * (1 + sx / c(30+x))

To simplify P, we need these identities:
cos(A+B) = cos(A)cos(B) − sin(A)sin(B)
cos(A−B) = cos(A)cos(B) + sin(A)sin(B)

Removing the annoying denominator, let k = c(30-x) * c(30+x)

k P
= (c(30+x) - sx) * (c(30-x) + sx)
= k + sx^2 + sx * (c(30+x) - c(30-x))
= k + sx^2 + sx * (-2 s(30) sx)
= k + sx^2 − sx^2
= k
-> P = 1

All factors can considered value of 1, thus C = 1

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02-12-2019, 07:58 PM **Post: #14**

Albert Chan
Senior Member

Posts: 624
Joined: Jul 2018

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

Prove E = -1:

This one is easy. Just do the first term, using shorthand c(#) = c# = cos(#°)

(2 c4 - 1/c4) = (2 c4^2 - 1) / c4 = c8 / c4

Numerator and denominator for everything cancelled out, except c(2^26)/c(4)

c(2^26) = c(2^26 mod 360) = c184 = -c4

-> E = -c4/c4 = -1

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02-14-2019, 04:12 AM (This post was last modified: 02-14-2019 04:21 AM by Albert Chan.) **Post: #15**

Albert Chan
Senior Member

Posts: 624
Joined: Jul 2018

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

> **Albert Chan Wrote:** (02-12-2019 05:37 AM)
> B = 1/(sin(45°)sin(46°)) + 1/(sin(46°)sin(47°)) + ... + 1/(sin(89°)sin(90°))

I got the prove !!!

Prove B = 1/sin(1°), using shorthand c(#) = c# = cos(#°), s(#) = s# = sin(#°):

Identities required:
cos(A+B) = cos(A)cos(B) − sin(A)sin(B)
cos(A−B) = cos(A)cos(B) + sin(A)sin(B)
cos(2*A) = 2*cos(A)² - 1

Replace sine with cosines, **B = 1/(c0c1) + 1/(c1c2) + ... 1/(c44c45)**

Sum 2 terms: 1/(c0c1) + 1/(c1c2)
= (c2+c0)/(c0c1c2)
= (2*c1c1) / (c1c2)
= 2*c1/c2

Sum 3 terms: 2*c1/c2 + 1/(c2c3)
= (2*c1c3 + 1)/(c2c3)
= (c2 + c4 + 1)/(c2c3)
= (c2 + 2*c2^2)/(c2c3)
= (1 + 2*c2)/c3

Sum 4 terms: (1 + 2*c2)/c3 + 1/(c3c4)
= (c4 + 2*c2c4 + 1)/(c3c4)
= (2*c2^2 + 2*c2c4)/(c3c4)
= 2*c2*(c2+c4)/(c3c4)
= 2*c2*(2*c1*c3)/(c3c4)
= 4*c1c2/c4

Sum 5 terms: 4*c1c2/c4 + 1/(c4c5)
= (4*c1c2c5 + 1)/(c4c5)
= (2*c2*(c4+c6) + 1)/(c4c5)
= (2*c2c4 + 2*c2c6 + 1)/(c4c5)

= (2*c2c4 + c8 + c4 + 1)/(c4c5)
= (2*c2c4 + 2*c4^2 + c4)/(c4c5)
= (1 + 2*c2 + 2*c4))/c5

Finally see a pattern! It can be proved by induction (not shown):

B = (1 + 2*c2 + 2*c4 + ... + 2*c44)) / c45

Sines and Cosines of Angles in Arithmetic Progression formulas:

sin(x) + sin(x+y) + ... + sin(x+(n-1)*y) = sin(x+(n-1)y/2)*sin(ny/2)/sin(y/2)
cos(x) + cos(x+y) + ... + cos(x+(n-1)*y) = cos(x+(n-1)y/2)*sin(ny/2)/sin(y/2)

B = (1 + 2*(c2 + c4 + ... + c44)) / c45, with x=y=2°,n=22
= (1 + 2*(c23 s22 / s1)) / c45
= (1 + 2*(c23 c68 / s1)) / c45
= (1 + (c91 + c45) / s1) / c45
= (1 - s1/s1 + c45/s1) / c45
= 1/sin(1°)

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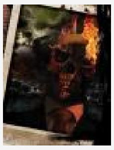
02-14-2019, 05:33 AM **Post: #16**



Carsen
Member

Posts: 163
Joined: Jan 2017

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

Solutions with RPL. These programs are designed to not be flexible. Only to solve the problem.

Code:

```
Spoilers for A








<<
```

Code:

```
Spoilers for B








<<
```

Code:

```
Spoilers for C





<<
```

Code:

```
Spoilers for D





<<
```

Code:

```
Spoilers for E





<<
```

Fun programming.

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02-14-2019, 06:08 AM **Post: #17**

Albert Chan
Senior Member

Posts: 624
Joined: Jul 2018

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

> **Albert Chan Wrote:** (02-14-2019 04:12 AM)
> **B = (1 + 2*c2 + 2*c4 + ... + 2*c44)) / c45**

Another way, using **2 sin(A) cos(B) = sin(A+B) + sin(A-B)**

B sin(1°)
= (s1 + 2*s1c2 + 2*s1c4 + ... + 2*s1c44) / c45
= (s1 + (-s1 +s3) + (-s3 + s5) + ... + (-s43 + s45)) / c45
= s45 / c45
= 1

02-14-2019, 03:23 PM (This post was last modified: 02-14-2019 03:33 PM by Albert Chan.) **Post: #18**

Albert Chan
Senior Member
Posts: 624
Joined: Jul 2018

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

Got a very elegant and general proof that B = 1/sin(1°):

1/(c0c1) + 1/(c1c2) + ... + 1/(c(n-1)c(n)) = tan(n°) / sin(1°), assumed n < 90

Proof above by induction:

For n=1, 1/(c0c1) = 1/c1 = tan(1°) / sin(1°)

Assume this work for n=k, add 1 more term, we got:

tan(k°) / sin(1°) + 1/(ck c(k+1)) = (sk c(k+1) + s1) / (s1 ck c(k+1))

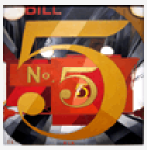
Since s1 = s((k+1) - k) = s(k+1) ck - c(k+1) sk, we got:

Sum of k+1 terms = (s(k+1) ck) / (s1 ck c(k+1)) = tan((k+1)°) / sin(1°)

QED.

-> With 45 terms, B = tan(45°) / sin(1°) = 1/sin(1°) 🙂

02-24-2019, 08:17 PM (This post was last modified: 02-24-2019 09:15 PM by Valentin Albillo.) **Post: #19**



Valentin Albillo
Senior Member
Posts: 347
Joined: Feb 2015
Warning Level: 0%

RE: [VA] SRC#004- Fun with Sexagesimal Trigs

.
Hi, all:

A short proof of the evaluation of B:

$$B = \frac{1}{sin\ 45^o\ sin\ 46^o} + \frac{1}{sin\ 47^o\ sin\ 48^o} + \ldots + \frac{1}{sin\ 133^o\ sin\ 134^o} = \frac{1}{sin\ 1^o}$$

1) First, we multiply both sides by *sin 1º*:

$$\frac{sin\ 1^o}{sin\ 45^o\ sin\ 46^o} + \frac{sin\ 1^o}{sin\ 47^o\ sin\ 48^o} + \ldots + \frac{sin\ 1^o}{sin\ 133^o\ sin\ 134^o} = \frac{sin\ 1^o}{sin\ 1^o} = 1$$

2) Now we use the identity

$$\frac{sin((k+1)^o - k^o)}{sin\ k^o\ sin(k+1)^o} = cot\ k^o - cot(k+1)^o$$

which transforms the left-hand side into this:

$$cot\ 45^o - cot\ 46^o + cot\ 47^o - cot\ 48^o + \cdots + cot\ 133^o - cot\ 134^o$$

3) Then we reorder the terms in the sum like this:

$$cot\ 45^o - (cot\ 46^o + cot\ 134^o) + (cot\ 47^o + cot\ 133^o) - \cdots + (cot\ 89^o + cot\ 91^o) - cot\ 90^o$$

4) All the terms inside the parentheses cancel out because they feature supplementary angles (cot Nº + cot (180º-Nº) = 0), so the expression reduces to:

$$cot\ 45^o - cot\ 90^o = 1 - 0 = 1$$

Q.E.D. :)

Thanks for your interest and have a nice weekend.
V
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