Developing a Standard Hand Phantom for Wireless Testing

A standardized hand phantom used together with the SAM head phantom for radiated performance testing mirrors real-world use.

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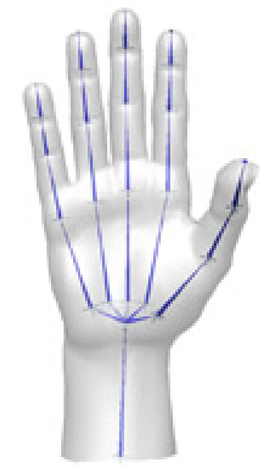


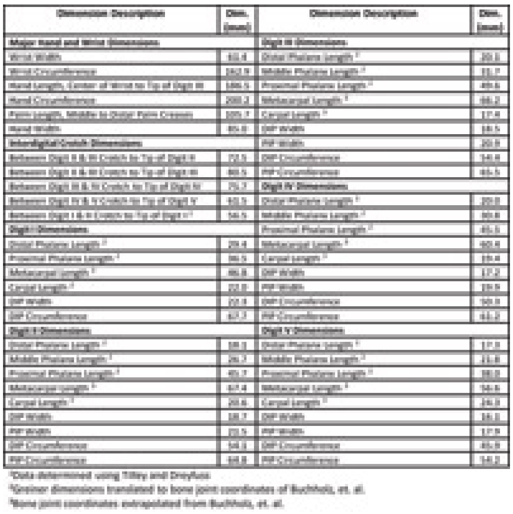
In the early ‘90s, the IEEE began working on a standardized model for the human head and upper torso for use in Specific Absorption Rate (SAR) testing of wireless devices. In the early ‘90s, the IEEE began working on a standardized model for the human head and upper torso for use in Specific Absorption Rate (SAR) testing of wireless devices. This SAM Head Phantom (SAM = Standard Anthropomorphic Model or Specific Anthropomorphic Mannequin depending on the reference) was based on the 90th percentile human male head dimensions as determined by a study of US Army personnel performed in the late ‘80s. Even before the completion of SAR test standards such as IEEE 1528-2003,[1] US mobile phone manufacturers and wireless carriers adopted a head and neck only version of this SAM Phantom for use in evaluating the over-the-air radiated performance of mobile phones. In this application, the goal of the phantom is to determine the impact of the human head upon the total radiated power of the mobile device, rather than evaluating the energy absorbed within the head. Since then, this same head has been adopted by a variety of organizations, including the CTIA, Wi-Fi Alliance, WiMAX Forum, and 3GPP, for their over-the-air radiated performance testing programs.[2-5] Until now, all of these test methods have evaluated the performance of a mobile phone by attaching it to the side of the head phantom and monitoring radiated power or receiver sensitivity from all directions around the device. Unfortunately this scenario does not really reflect real world usage, since users rarely walk around with their mobile phones strapped to the sides of their heads! Thus, there has been a long standing desire to develop a standardized hand phantom that can be used together with the SAM Head Phantom for realistic radiated performance testing.

Figure 2. Sample of the Standard Hand Phantom in a typical grip.

The dozen or so joints in the human hand makes the development of a hand phantom significantly more complex, because unlike the head — which maintains a rather constant shape — a user's hand will naturally change its geometry to fit a variety of device shapes and individual tendencies. In addition to being a standard size, a standardized hand phantom has to support adaptation to this wide variety while still providing a level of measurement reproducibility when used to determine the radiated performance of a mobile phone. The material makeup and corresponding electrical properties of the human hand are also different from those of the human head, requiring a different dielectric medium than that used for the SAM Head Phantom. Thus, a careful review of human factors, material properties, handset shapes, and industry trends is required so that optimal decisions about finger placement can be made. Evaluation of all of these factors is necessary to ensure that antenna designers and wireless carriers have a realistic and reliable model to use when comparing handset performance.

A group of test equipment vendors, test labs, mobile phone manufacturers, and wireless carriers have spent the past two years developing a set of standard hand phantoms to address a variety of usage cases. This article describes the process followed and the results that were achieved .

The Human Hand
For a number of years leading up to this effort, different manufacturers and test labs attempted a variety of approaches to creating a human hand phantom. These



Dimension Description	Dim. (mm)	Dimension Description	Dim. (mm)
Major Hand and Wrist Dimensions:		Digit III Dimensions:	
Wrist Width	61.4	Distal Phalanx Length	20.1
Wrist Circumference	162.9	Middle Phalanx Length	31.7
Hand Length, Center of Wrist to Tip of Digit III	186.5	Proximal Phalanx Length	49.6
Hand Circumference	200.2	Metacarpal Length	66.2
Palm Length, Middle to Distal Palm Creases	101.7	Carpal Length	17.8
Hand Width	85.0	DIP Width	18.5
Interdigital Crotch Dimensions:		PIP Width	20.9
Between Digit II & III Crotch to Tip of Digit II	72.5	DIP Circumference	54.8
Between Digit II & III Crotch to Tip of Digit III	80.5	PIP Circumference	65.5
Between Digit III & IV Crotch to Tip of Digit IV	75.7	Digit IV Dimensions:	
Between Digit IV & V Crotch to Tip of Digit V	63.5	Distal Phalanx Length	20.0
Between Digit I & II Crotch to Tip of Digit I	56.5	Middle Phalanx Length	30.8
Digit I Dimensions:		Proximal Phalanx Length	45.5
Distal Phalanx Length	29.4	Metacarpal Length	60.4
Proximal Phalanx Length	36.5	Carpal Length	19.4
Metacarpal Length	46.8	DIP Width	17.2
Carpal Length	22.8	PIP Width	19.9
DIP Width	22.8	DIP Circumference	50.9
DIP Circumference	67.7	PIP Circumference	61.2
Digit II Dimensions:		Digit V Dimensions:	
Distal Phalanx Length	18.1	Distal Phalanx Length	17.9
Middle Phalanx Length	26.7	Middle Phalanx Length	21.8
Proximal Phalanx Length	45.7	Proximal Phalanx Length	38.0
Metacarpal Length	67.4	Metacarpal Length	56.6
Carpal Length	20.6	Carpal Length	24.3
DIP Width	18.7	DIP Width	16.1
PIP Width	21.5	PIP Width	17.9
DIP Circumference	54.1	DIP Circumference	45.9
PIP Circumference	64.8	PIP Circumference	54.2

1 Data determined using Tilley and Dreyfuss
2 Greiner dimensions translated to bone joint coordinates of Buchholz, et. al.
3 Bone joint coordinates extrapolated from Buchholz, et. al.

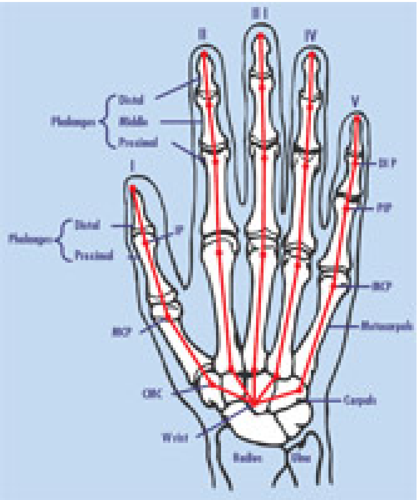
[1]

click to enlarge
[1]Data determined using Tilley and Dreyfuss [2]Greiner dimensions translated to bone joint coordinates of Buchholz, et.al [3]Bone joint coordinates extrapolated from Buchholz, et al

solutions ranged from a latex glove filled with tissue simulant fluid and a posable plastic "skeleton", to a gel filled glove, to rubber molds made from an employee's hand in order to cast carbon or ferrite loaded phantoms. The result was a wide variety of hand shapes and sizes being used to try to determine the same radiated performance data. Not surprisingly, these fell far from the mark of a standardized hand, and had a limited basis on any real-world data. Since then, usage studies performed to determine how users hold and use a mobile phone have shown a wide range of applications (against the head vs. hand-only for dialing, data, and navigation applications) and ways of holding a given phone. In addition to the need to simulate different usage applications, it became apparent that different styles of phones were typically held in considerably different ways. These variations in hand dimension, grip, and material composition could have significant impact on the radiated performance of a device, and thus would directly impact the antenna design. If a standard hand phantom used during design and testing does not closely match the way a user would actually use the device, then it's likely that the resultant performance will differ from that determined using the phantom. In the worst possible case, a poorly chosen hand phantom could result in a phone design that performs well in testing, but has an antenna that is covered by the hand in actual use. Thus, it was necessary to not only standardize the hand dimensions, but also to standardize the hand shape for a given task and style of mobile phone.

In order for a standardized hand to be used to replicate typical real-world results it must represent the "average" human hand. Too large, and phone designers might overdesign the phone to compensate for the blocking effect of the hand; too small, and the resulting phone designs might still have poor real world performance for most users. Similar to the original SAM Head Phantom design, it was important that the standard hand phantom be based on anthropomorphic studies to provide statistical backing for the hand dimensions that were chosen.

Greiner's Hand Anthropometry of US Army Personnel[6], sponsored by the Anthropology Branch at the Army NATICK Research Development and Engineering Center, is perhaps the largest and most comprehensive modern anthropometric study available. A sample size of 1003 men and 1304 women had their hands photographed, digitized, and measured in a total of 86 anthropometric dimensions. Measurements were taken from a number of landmarks on the hand, including creases in the skin of the hand, the tips of fingers, and other visible locations. Unfortunately, although this study includes many direct measurements of pertinent data, there are some hand dimensions that were not included. Thus, it was necessary to combine these measurements with measurements from other references in order to fill in the missing dimensions.



[2]

click to enlarge
Figure 3. Segments and dimension points of the human hand.

Tilley and Dreyfuss' *The Measure of Man and Woman: Human Factors in Design*[7] includes some data regarding hand anthropometry, but is far from complete in defining all of the physical dimensions required for a hand phantom model. Although the book does recognize the Greiner study as an available data source, it does not state the source of the data presented in the book. Nonetheless, by correlating dimensions that overlap between the two references, it is possible to fill in some of the gaps in Greiner's data.

Finally, Bugbee and Botte's article "Surface Anatomy of the Hand: The Relationships Between Palmar Skin Creases and Osseous Anatomy"[8], which was a study performed on 48 adult corpse hands and 5 live human hands, finds the relationship between the hand skin creases and the bone joint locations. By combining this reference with the dimensions in Greiner that specifically reference skin creases, it was possible to determine the desired finger digit link lengths.

The resulting dimensions from the 50th percentile of the men's hand and women's hand were then averaged together in order to produce a standard hand phantom that lies in the middle of the expected range of users.

The Kinematic CAD Model
A number of published and internal grip studies helped to identify patterns and commonalities in the way different users position their fingers on devices of various

shapes and in different modes of usage. Preliminary experiments with both human subjects and prototype hand phantoms confirmed that finger placement played a significant role in affecting total radiated power (TRP) and antenna tuning, and would need to be standardized to ensure repeatable measurements. It quickly became apparent that no single grip could accommodate all devices and use cases, thus there was a requirement for an advanced 3D CAD model hand that, once its proportions were set, could be posed as needed to produce a variety of moldable grips.

The design of such a "kinematic" CAD hand is complicated by the fact that skin creases used by researchers to measure hand dimensions do not precisely correspond to the internal axes of rotation of human finger joints. Addition of a realistic, posable "bone structure" correctly proportional to the CAD hand was done with reference to Buchholz, Armstrong, and Goldstein's "Anthropometric Data for Describing the Kinematics of the Human Hand." The fingers of the resulting CAD model could then be bent as needed to produce natural human grips.

Figure 3 illustrates the segments of the human hand, while Table 1 summarizes the various dimensions resulting from combining the aforementioned studies. Unless otherwise noted, the dimensions were based on data found in the Greiner study. Figure 1 illustrates the resulting kinematic CAD models.

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Editor's Note: *The is the first of a three part series. Part 2 will appear in the December issue of WDD.*

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